MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES
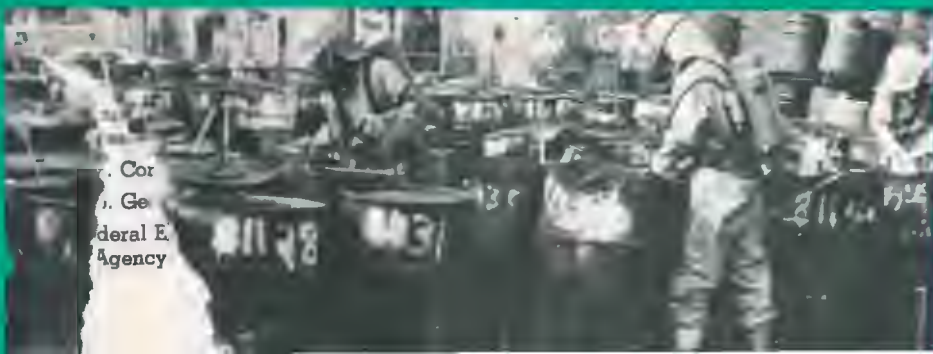
THE 5TH NATIONAL CONFERENCE ON

MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES

NOVEMBER 7-9, 1984 • WASHINGTON, DC

AFFILIATES

PREFACE

CERCLA will place the states in the implementing role and will delegate responsibilities to the EPA Regional Administrators. In the implementation of the CERCLA programs, new sites will be identified and new technologies will be developed and employed.

Under CERCLA, the U.S. EPA has three major elements of its strategy. First, uncontrolled hazardous waste sites in the Agency's current inventory will be assessed. Second, those sites which present an imminent threat to public health or the environment will be stabilized. Third, those sites that should receive priority attention for remedial clean-up action will be dealt with first, using the National Contingency Plan for guidance.

As of July 1984, EPA indicated that they had begun remedial investigations and feasibility studies at 258 NPL sites, 60 NPL sites are being cleaned up, and emergency clean-ups had been initiated at 400 sites, NPL and non-NPL. In addition, seven sites on the NPL are being cleaned up by private groups under EPA supervision.

In FY 1985, CERCLA is expected to be extended at an increased funding level. Much of the increase in these resources will be devoted to expansion of remedial construction projects at NPL sites. During FY 1985, EPA plans to begin construction work at 46 sites, compared with 15 sites during FY 1984. By the end of FY 1985, EPA expects to complete or have under way planning activities for cleanup at 396 NPL sites.

In October 1981, EPA published an interim priority list of 115 sites and in July 1982, expanded the eligibility list adding 45 sites for a total of 160 sites. EPA published a list of 418 sites as a proposed rule in December 1982, including 153 of the 160 sites previously published. Times Beach, Missouri, was proposed in March 1983, bringing the total proposed to 419. After a period of public comment, EPA published the NPL as a final rule in August 1983. At the same time, EPA proposed 133 new sites in its first NPL update. In the second NPL update, released October 1984, EPA proposed 128 sites be added to the NPL and modified some existing sites. The NPL, as of November 1984, consists of 538 confirmed and 244 newly proposed sites plus four remaining from the 1983 proposed list. This second update is included in the Appendix. Refer to the *1983 Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites* for the original NPL and the October 1983 update.

The papers presented at the National Conference on Management of Uncontrolled Hazardous Waste Sites update the significant technology and information necessary to identify and evaluate uncontrolled hazardous waste sites and control and mitigate the consequences from those sites on the National Priorities List. These *Proceedings* emphasize actual experience obtained during the various stages necessary for remediation of the numerous SUPERFUND sites.

ACKNOWLEDGEMENT

CONTENTS

FEASIBILITY STUDIES OF GROUNDWATER POLLUTION SOURCE IDENTIFICATION FROM ACTUAL FIELD MONITORING WELL DATA

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INTRODUCTION

Locating a pollution source is perhaps the single most important aspect of groundwater pollution, isolation and cleanup. Conventional methods of locating an unknown source require an extensive number of observation wells from which sufficient data can hopefully be obtained to plot concentration contours for identifying the source location.

Only recently, the use of numerical methods has been investigated. Computer modeling is helpful because use of a limited amount of well data allows one to back calculate to determine the likely source. This process is called "inverse problem" or "parameter identification problem". An operative computer model requires only a few wells to effect a solution. The economic implications of requiring only a few wells are obvious.

Two different approaches were used for the numerical identification: nonsequential and sequential optimization. For the former, the optimization is applied to the partial differential equation of groundwater solute transport. For the latter, the partial differential equation is spatially discretized and is rearranged into a standard form of linear dynamic system. The optimization is then applied to the dynamic equation.

A typical nonsequential approach was described in a paper by Gorelick et al.[1] in which the optimization methods of linear programming and multiple regression were combined with numerical simulation of groundwater solute transport to identify the location and magnitude of groundwater pollutant sources.

As a sequential approach, the development of analytic formulations and methodology using sensitivity theorem was described in the author's earlier paper.[2] The computer codes based on the algorithms so developed were applied to field situations. Two cases of field application will be presented in this paper. For the sake of clarity, the basic principles of the methodology will be outlined first.

BACKGROUND

The spatially discretized partial differential equation of groundwater solute transport using finite element method can be written as:

$$M\left\{\dot{c}\right\} + (K-A+E)\left\{c\right\} - \left\{p\right\} = 0 \tag{1}$$

in which

$\left\{c\right\}$ = concentration vector representing the concentration the pollutant at each nodal point

$\left\{\dot{c}\right\} = \left\{\dfrac{dc}{dt}\right\}$ time derivative of the concentration vector

K, A, E and M = coefficient matrices, dispersion, convection, first order decay and mass matrix respectively.

$\left\{p\right\}$ = forcing vector

If the boundary conditions prescribed are of Neumann type with normal derivative equal to zero and there are isolated sources within the domain confined by the boundary, it can be shown that the forcing vector, $\left\{p\right\}$, has zero entries except at the "source" nodes where the entry values are related to the magnitudes of the pollutant at corresponding source nodes. Thus, the problem of locating a pollution source from limited well data is equivalent to identify the forcing vector $\left\{p\right\}$ in Equation 1 for some given entry values in the concentration vector $\left\{c\right\}$ at some discrete instant in time.

The sensitivity theorem for a linear dynamic system[3] provides a recurrent formula for updating $\left\{p\right\}$ in a manner so as to minimize the error (sum of the square of the differences between estimated and measured concentrations at monitoring wells). The reader is referred to the original paper[2] for detailed derivations.

The computer programs enable the user to identify the source location of groundwater pollution using the existing limited data. If the preliminary computer prediction is not decisive, it can suggest a neighborhood for drilling locations of additional monitoring wells. With additional new sets of concentration data as input to the computer program, the prediction is expected to improve in the subsequent computer run. Thus, the neighborhood of the suspected source location is narrowed. By repeating the process, one may eventually pinpoint the source location.

Ecology and Environment, Inc., provided Drexel University hydrogeologists information of the site including groundwater table elevation, geological formation, well location and description, brief history of the site and laboratory report sheets of chemical analysis of the groundwater samples from the monitoring wells. The computer prediction made by the Drexel team was then checked by Ecology and Environment, Inc. against the actual findings from the field investigation—results which were not released to the Drexel team before running the computer programs. Two cases of field applications will be described in the following sections.

CURTISS WELL CASE

Description of the Site

The Curtiss Well pollution Site is located in Southington, Connecticut (Fig. 1). In the figure, the encircled area (1500 ft by
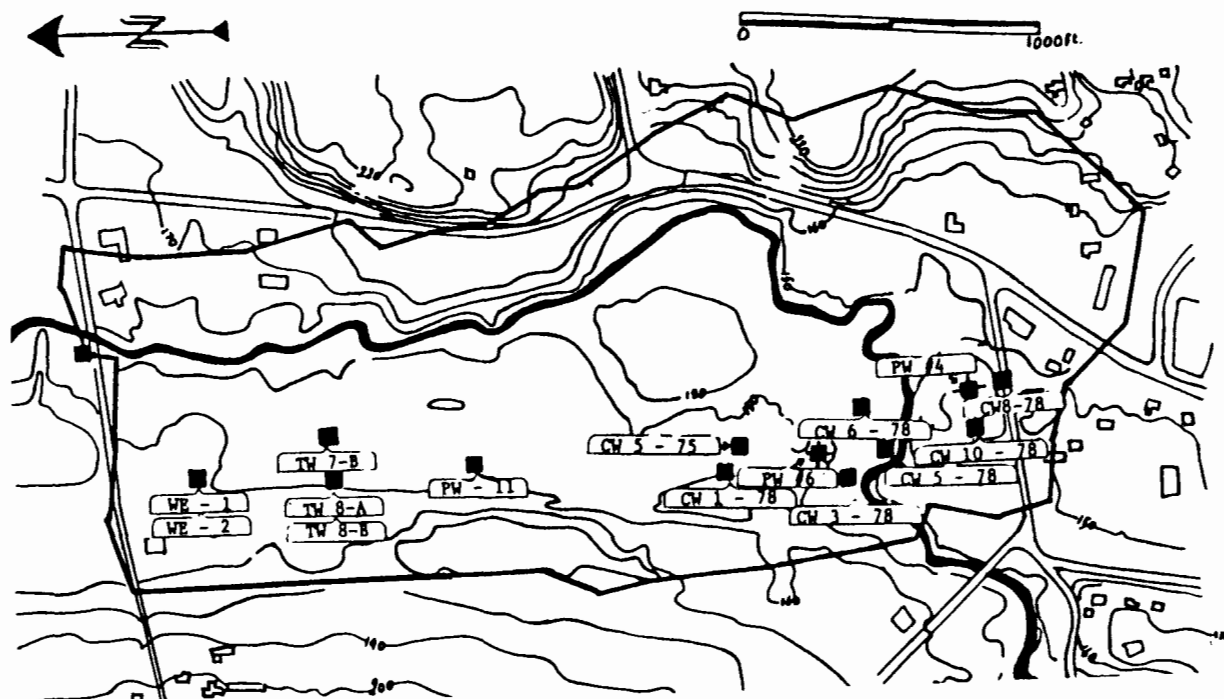
Figure 1
Topography of the Studied Area and the Location of Wells in the Curtiss Well Site

4000 ft) is the domain of the numerical solutions. The area of interest is mostly covered by a sandy, locally silty, formation which overlays the bed rocks. The Quinnipac River runs north-south halfway across the region and then turns southwest leaving the area.

Production well #4 (Fig. 1) has been in operation, pumping at a rate of 380 gal/min, since 1955. Due to the demand for water, an additional production well (well #6) on the other side of Quinnipac River was developed. When the new production well began operation in 1976, its water was found to contain a high concentration of organics. Similar results were also found in production well #4 later. Both wells were capped in 1976.

An initial investigation found that there was a surface ponding of industrial organic waste during the 1950s and 1960s. This discovery started the extensive site investigations of the area. A number of monitoring wells were installed, and the results of chemical analyses for the groundwater quality were compiled in 1980, 1981 and 1982.

Among the dissolved organics in groundwater, TCE (trichloroethylene) was chosen for the modeling of the groundwater solute transport in the studied area. The measurements from the samples at the wells with significant TCE concentrations were summarized in Table 1. The locations of the wells are shown in Figure 1.

Solution Procedures and Results

There are three separate programs in the computer package for source location identification. The first program computes the nodal head values. The output of the first program will be incorporated in the input file to the second program which computes the velocity components at each node. The values of nodal velocities are then used by the third program which predicts the distribution of the strength of the groundwater pollution source.

For the preparation of input files to these programs, one has to set up a grid system for the discretized site and determine several model parameters. As shown in Figure 2, the Curtiss Well Site is discretized into 96 quadrilateral elements with 119 nodes.

A non-uniform but steady flow field was used. It was felt that groundwater table contours at pumping conditions (production well #4 pumping at a constant rate of 380 gal/min) would be more appropriate than that of natural conditions (no pumping) for this source identification study. The depth of aquifer varies across the study site; the variation in depth is shown in Figure 3. It is assumed that TCE is instantaneously mixed with water, and the concentra-

Table 1
TCE Concentration Measurements at Curtiss Well Site

Well No.	Node No.	TCE conc.	date	TCE conc.	date	TCE conc.	date
SW-5	1	0.4	3/80	0.8	6/17/81	210	8/11/82
WE-1	10	0.6	3/80	6.8	6/17/81	15	8/11/82
TW-8A,B	27	700K	3/80	36.5K	8/11/82	~0K	9/15/8:
TW-7	28	270	3/80	340	8/11/82		
TW-11	40	25.5	3/80	5	9/15/8:		
CW-1-78	60	1.8	6/15/81	32	9/15/82		
CW-5-78	61	0.1	3/80	60	9/15/8:		
PW#6	69	1.0	3/80	4.2	7/7/81	2.0	9/15/82
CW-7-78	78	120	6/15/81				
CW-6-78	79	7.7	3/80	3.0	9/15/82		
CW-5-78	90	1.7	6/15/81	4.0	9/15/82		
CW-10-78	101	7.0	3/80	1.7	6/15/81	<0.1	9/15/82
CW-8-78	104	7.0	3/80	1.7	6/15/81		
PW#4	105	4.7	3/80	2.8	6/17/81		7/7/81

Note: All concentrations in µg/l.
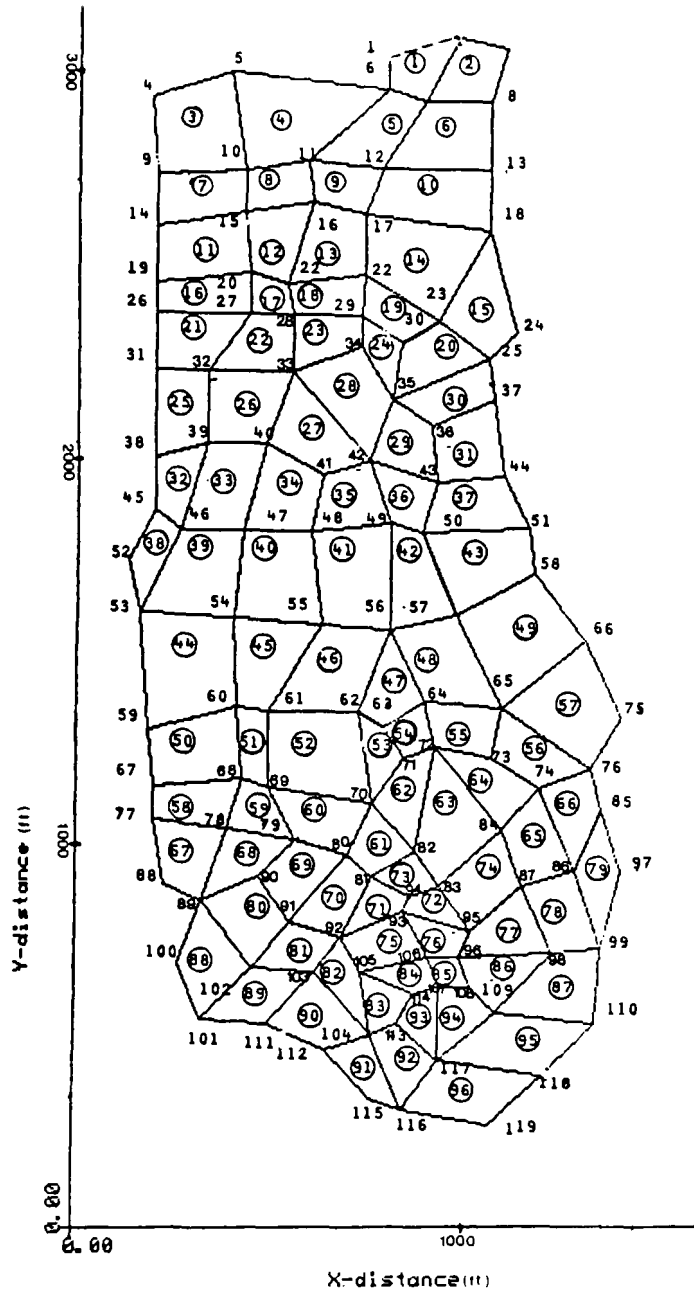
Figure 2
The grid system of Curtiss Well Site

Figure 3
Aquifer Thickness Variation in Curtiss Well Site

tion is uniform at any vertical plane. Thus, depth-averaging approximation applied. The computed nodal velocity distributions are graphically presented in Figure 4.

Since no field measurements are available for the dispersion coefficients, the selection of these values was made using values from the literature. The molecular diffusion is assumed small compared to the hydrodynamic dispersion. Values of 205 ft for longitudinal dispersivity and 12.9 ft for transversal dispersivity were used.

TCE could be adsorbed on the solid phase of the aquifer. However, the retardation effect is believed to be small and will not seriously affect the qualitative prediction of source identification. That is, the retardation factor of 1 was used for this study. TCE is slightly soluble in groundwater. The concentration measurements from observations wells are considered as dissolved TCE. Thus, the transport of TCE in this site study is assumed to be dissolved pollutant dispersed in and convected by the groundwater. The values of model parameters are listed in Table 2.

The computed results clearly indicate that there is an area-source (encircled by nodes 19, 20, 26 and 27) in the northwest side of

Quinnipac River and a point source (at node #115) south-southwest to the production well #4 (Fig. 5). Also shown in the figure are the locations of a surface lagoon and the suspected point source based on field investigation. The computer projections were satisfactory. The target of point source was missed by approximately 200 ft.

LOWRY LANDFILL SITE

Description of the Site

The Lowry Landfill is located in Arapahoe, Denver, Colorado. The studied area, approximately 13,000 ft by 12,000 ft, is covered by the undifferentiated Denver and Dawson formations which are comprised of (from the bottom to the top) coal, siltstone-claystone and sandstones. The formations are overlain locally by a recent quaternary alluvial and over burden materials around the effluent streams in the area.

The observation wells drilled within the alluvial (10 to 30 ft in depth) are designated as A-wells (alluvial wells). The observation wells with depth greater than 30 ft drilled into the Denver and Sawson formations are designated as B-wells (bedrock wells). The locations of these wells are shown in Figure 6.

Table 2
Model Parameters Used in Computer Program

	Curtiss Well Site	Lowry Landfill Site
No. of elements	96	76
No. of nodes	119	98
No. of wells	14	9
Hydraulic conductivity	28.3 ft/day	0.74 ft/day
Lateral dispersivity	205 ft	20.4 ft
Transversal dispersivity	12.9 ft	1.29 ft
Retardation factor	1	1
First order decay constant	0	0
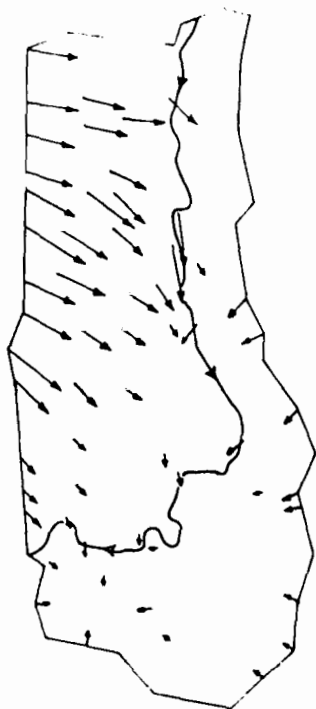
Figure 4
The Velocity Field in Curtiss Well Site

Figure 6
Topography and the Location of Wells in Lowry Landfill Site

Figure 5
The Predicted Source Locations and the Actual Finding from the Field Investigations
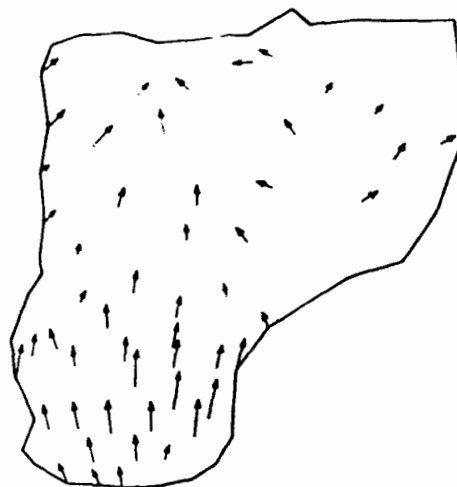
Figure 7
The Velocity Distribution in Lowry Landfill Site

The Lowry municipal sanitary and industrial waste landfill is located to the west of a military reservation. The landfill was opened in 1964; in 1967, the City of Denver authorized dumping liquid hazardous wastes. It was estimated that approximately 100,000,000 gal of the liquid wastes were dumped between 1967 and 1980.

Significant concentrations of hazardous organics began to appear in the groundwater samples in several of the monitoring wells. A number of new monitoring wells were installed, and the results of chemical analyses for the groundwater quality were compiled in 1981, 1982 and 1983.

Procedures and Results

The procedures utilized in this study are essentially the same as described in the previous section: field discretization, estimation of parameters and nodal velocity computations. The parameters and their values were listed in Table 2, and the velocity field was plotted in Figure 7. For simplicity, other information will not be presented here.

The computer predictions based on TCE transport were plotted in Figure 8. The shaded area encircling nodes 59 and 60 is the primary source location. The secondary source area includes nodes 58, 65, 64, 77, 70, 66, 72, 67 and 54, and the other secondary source area is the surrounding of node 91. Since the groundwater is flowing from south to north and node 91 is located south to the primary source nodes 59 and 60, it is unlikely that the high concentrations of TCE detected near node 91 are transported from nodes 59 and 60. It may be that the landfill covers a larger area. Indeed, it has been reported that various industrial wastes were dumped at differ-
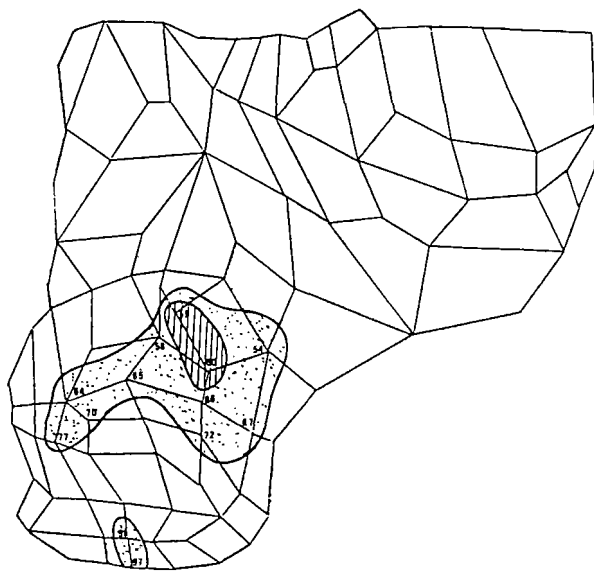
Figure 8
The Distribution of Source Strength for TCE

Figure 9
The Composite Area Contaminant Source and the Locations of
Burial CElls

ent locations within the large area landfill. To obtain better boundary of the large area contaminant source, 1,1-Dichloroethane and total organics were selected for the modeling in addition to TCE.

The composite area source which was obtained by superimposing the predicted area sources for all three species is shown in Figure 9. Also, shown in the figure are the locations of burial cells found in the field. As can be seen, the projected sources fall relatively within these areas.

CONCLUSIONS

The general problem of locating a pollution source by having data from a limited number of observation wells is quite challenging, yet worthwhile. Major advantages are the shorter time and lower costs involved compared to the conventional method of pollutant contour mapping. It has been demonstrated in the author's earlier paper[2] that the proposed method can accurately identify a pollution source location with a limited number of observation wells using hypothetical data.

In this study, the test of feasibility of using these computer models has been carried one step further by applying the computer codes to two sets of real field data: Curtiss Well Site and Lowry Landfill Site. Based on the results, it can be concluded that the computer program can be developed into a useful tool. It holds the promise of being able to determine where additional wells should be located for an on-going pollution scheme.

ACKNOWLEDGEMENT

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INCORPORATION OF HYDROGEOLOGIC DATA INTO UNITED STATES ENVIRONMENTAL PROTECTION AGENCY/ ENVIRONMENTAL PHOTOGRAPHIC INTERPRETATION CENTER INVESTIGATIONS OF HAZARDOUS WASTE SITES

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INTRODUCTION

Environmental assessment using historic and current aerial photographs is the primary function of the USEPA's Environmental Photographic Interpretation Center (EPIC) in Warrenton, Virginia, a field station of the Environmental Monitoring Systems Laboratory, Las Vegas, Nevada. A major portion of EPIC's current workload is to provide photoanalytic support to federal Superfund investigations. In response to the need for hydrogeologic data in these investigations, EPIC has begun incorporating available hydrologic and geologic information into its reports. Two studies are presented which illustrate EPIC's initial efforts in this area.

NORTHWESTERN VIRGINIA SITE INVESTIGATION

Concerns about the possible effects of an industrial plant in northwestern Virginia on the surrounding community and environment arose after a contaminated well and a highly acidic pond were discovered in the vicinity of the plant. An analysis of historical aerial photographs was undertaken to document past activities and conditions at the site. In addition, an effort was made to locate the plant site within its regional geologic context since hydrogeologic conditions in the area were critical factors in determining potential pollutant pathways.

A search of government and commercial aerial photographic sources was undertaken to obtain the best quality photography available of the site for the period 1945 to 1979. Black and white photography was obtained for 1945, 1950, 1958, 1964, 1970 and 1976, and false color infrared photography was obtained for 1979. Sources of the black and white photography were the Agricultural Stabilization and Conservation Service (ASCS), the U.S. Geological Survey (USGS) and the Virginia Department of Transportation. The false color infrared photography was obtained from EPIC's in-house film library.

Each year of photography was analyzed for possible sources of pollution including tanks, ground stains, buildings, pipelines, impoundments, waste burial areas and on-site activities. The analysis was performed by stereoscopically viewing pairs of transparencies, backlit on a standard light table. By observing the site three-dimensionally, and at various magnifications, the analyst could search for objects, features and signatures associated with potential pollution sources. A land use and drainage survey of the study area was also performed.

Enlargements were made from coverages which revealed significant changes in the study area. Findings were annotated on overlays to these enlargements, and full descriptions were provided in an accompanying text.

The type of information that was obtained from the analysis of historical aerial photographs is shown in Figures 1 to 4. In 1945 (Fig. 1), the plant is being constructed, renovated or converted and a fill area (Fill 1) composed of earthen material and/or rubble is visible. By 1950 (Fig. 2), the plant is fully operational. This can be inferred, in part, by the presence of a coal pile. The initial fill area has been enlarged since 1945, and a new fill area (Fill 2) has been started in a former field.

By 1958 (Fig. 3), the second fill area has been greatly expanded and small amounts of standing liquid can be seen on its surface and borders. The first fill area does not appear to have received additional fill material. In 1964 (Fig. 4), the plant does not appear to be operating and no coal pile is present. The second fill area appears to have received additional material since 1958, and a large pond has formed adjacent to it. This pond has recently been determined to be highly acidic.

Geologic information was obtained from the Virginia Division of Mineral Resources and the U.S. Soil Conservation Service. This information included maps and accompanying descriptive materials on the study area's soils, surficial geology and bedrock geology. Overlays to photographic enlargements were produced using these sources.

A portion of the photographic overlay that depicts soil types in the vicinity of the site is shown in Figure 5.[1] Deep and well-drained loams and silt loams underlie the site and have clay or silty clay loam substrata (2B and 51C). Depth to bedrock and high water table are greater than 1.5 and 1.8m, respectively. The fill areas and pond identified in Figures 1 to 4 occur on these soils. The plant site borders on another soil unit which is characterized by thin soils and occasional bedrock outcrops (174B).

A portion of the photographic overlay which depicts the surficial and bedrock geology of the study area is shown in Figure 6.[2, 3, 4] Surficial deposits underlying portions of the plant site include permeable sand, clay and cobbles. Bedrock underlying the entire site is limestone and dolomite possibly interbedded with chert masses, sandstone, shale and/or conglomerate. In an unfractured state, limestones and dolomites are relatively impermeable to water, but solution of bedding planes, joints and faults may produce routes for rapid groundwater movements.

By utilizing basic geological information in conjunction with the results of aerial photographic analysis, the field investigator has

Figure 1
Industrial Site, 1945

Figure 2
Industrial Site, 1950

Figure 3
Industrial Site, 1958

Figure 4
Industrial Site, 1964
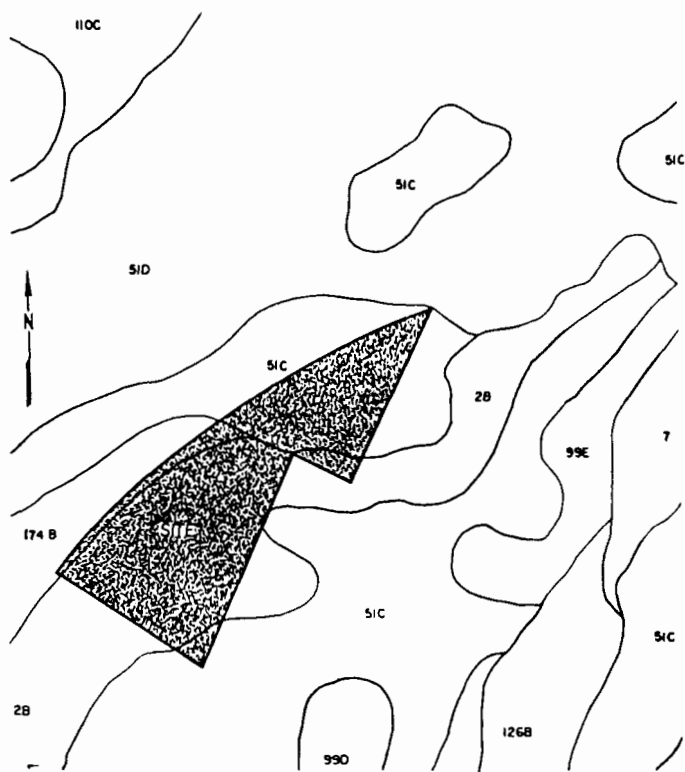
Figure 5
Soil Series
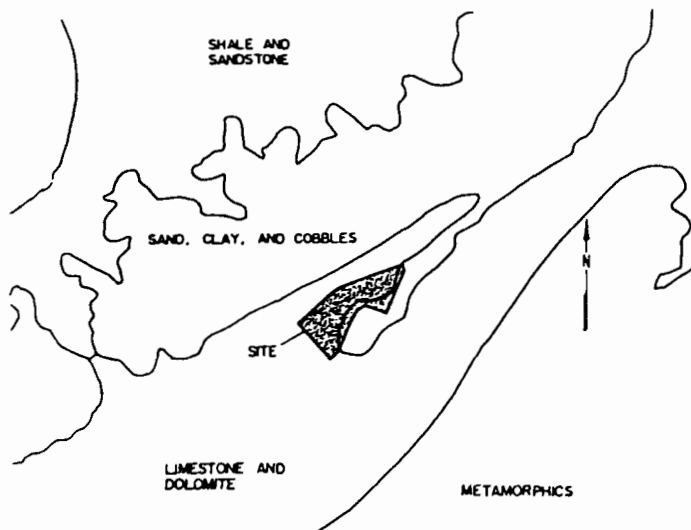
Figure 6
Surficial and Bedrock Geology

quest for a historical aerial photographic inventory and analysis of the Upper Merion Township, located in southeastern Pennsylvania.

The Upper Merion Township study area is a 3 km x 10 km rectangle in southeastern Pennsylvania incorporating Bridgeport, portions of Norristown, West Conshohocken, Valley Forge National Historical Park and the suburban, industrial and commercial development in the area (Fig. 7).

In the inventory, historical and current aerial photography were used to identify and describe sites that may contribute to groundwater contamination. Sites were regarded as potential groundwater contamination sources if they had been used for waste disposal or some other activity which may have had a negative impact on surface or groundwater quality. These sites included quarries (mostly abandoned), other old excavations, depressions, impounding basins, vacant lots, auto junkyards, industrial sites and landfill sites. Available hydrogeologic data, consisting of aquifer yield and surficial geologic maps, were included in the analysis.
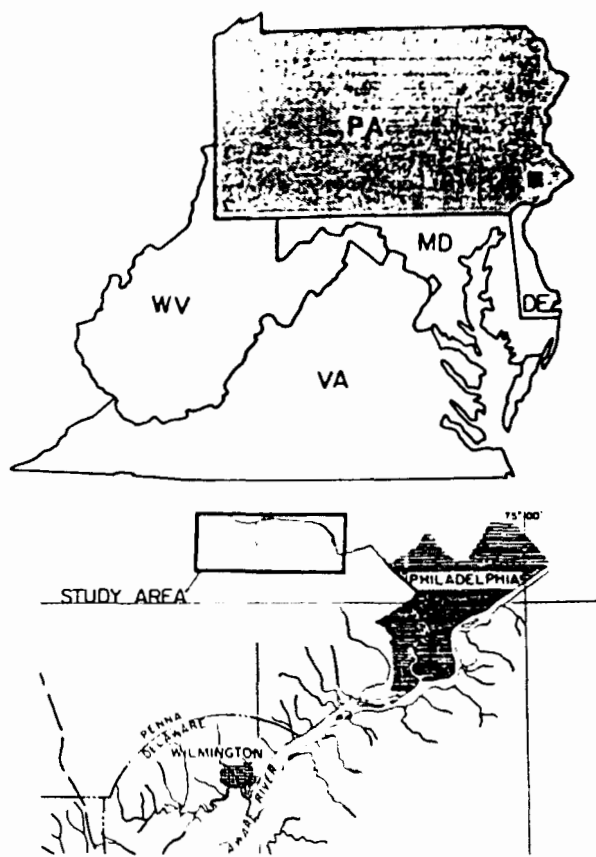
Figure 7
Location Map, Valley Forge & Norristown, PA Quads

gained a significantly greater understanding of conditions at the site prior to actually visiting the site. Thus, the investigator will not only be able to determine the likelihood of groundwater contamination at the site but also will know what to expect when a site visit is conducted.

REGIONAL INVENTORY

Investigations into waste disposal activity and the discovery of traces of chemical contamination in a local reservoir led to the re-

The site information gathered from the analysis of the historical aerial photography was compiled in textual and map form. The textual information is a description of the site as it appears on the aerial photography. It includes information on site size, the type of site, location of solid and liquid waste disposal areas, drainage pattern and other environmentally significant features. This analysis was done for each year of aerial photography so that the sequential development of each site could be understood. The locations of the sites as seen on the aerial photography were then transferred to a base map (Fig. 8).

Figure 8
Site Locations

The potential groundwater contamination site locations identified from the aerial photography were overlaid on the aquifer information maps (Fig. 10). When this was done, it became apparent which potential groundwater contamination sites fell above a particular aquifer. This allowed the user to access the potential threat to each aquifer relative to its potential value as a water resource.

Twenty of the sites are located in or just above these weathered carbonate aquifers. Within the study area, at least 38 quarries or excavations have been opened into these formations. Many of these have subsequently been filled. If these quarries were repositories for contaminated fill or hazardous waste, a direct conduit could exist for contaminants to enter the groundwater supply of these highly utilized formations. In fact, some wells in the carbonate rocks of the area have reportedly been abandoned because they are directly connected to polluted surface streams or other sources of pollution such as cesspools and waste disposal wells.[6]

These carbonate formations are especially susceptible to contamination from waste disposal activity due to the deep weathered zone containing large secondary openings that is overlain by a large number of potential contamination sites. In addition, the fact that these aquifers are heavily developed for public supply makes waste disposal in them particularly dangerous.

Hydrogeologic information from previous groundwater studies was obtained from the Commonwealth of Pennsylvania Department of Forests and Waters and the Department of Environmental Resources. This information included textual information describing the properties of the geologic units, maps depicting medium yield of wells drilled into the area aquifers and maps depicting local surficial geology. The maps showing the medium yield of drilled wells corresponded nicely to the surficial geology maps of the area; a simplified map showing the combination of this information was easily made (Fig. 9).

All of the rock types found in the Upper Merion Township can be expected to yield supplies of water and, therefore, are considered aquifers. However, the only aquifers in the area that can be expected to yield large supplies of water are members of the northeast-trending carbonate rocks (defined as sedimentary rocks composed of limestone and dolomite) that underlie a large portion of the study area. These carbonate rocks not only yield large quantities of water, but they are also highly developed for public water supply.[5, 6] The carbonate formations have been deeply weathered and the secondary openings greatly enlarged by solution. This weathered zone has a higher porosity than the unweathered rock, and where it does not contain large amounts of clay it may have a relatively high permeability. The median depth of this weathered zone is 12 to 23 m but can be as deep as 41 m or as shallow as 8 m.[5]

Water in this zone occurs chiefly under water table conditions and is recharged directly from precipitation.[5] Much of the groundwater discharged to streams probably passes only through this weathered zone, which is usually an important source of recharge to the fractures in the underlying bedrock.[5] Pollutants on the land surface or buried in this zone may be carried downward by infiltrating water to contaminate the surface water, the weathered zone and the underlying bedrock. The above is probably true of many formations, but the enlarged secondary openings of the carbonate formations may speed the movement of surface and subsurface water into the bedrock.

WELL YIELD LEGEND

- High Yield (200+ gpm)
- Medium Yield (110 gpm)
- Low Yield (50 gpm)

GEOLOGIC LEGEND

- Ledger Dolomite
- Conestoga Limestone
- Elbrook Formation (Limest

Figure 9
Well Yield and Geology

BRIDGEPORT

WELL YIELD LEGEND

- High Yield (200+ gpm)
- Medium Yield (110 gpm)
- Low Yield (50 gpm)

GEOLOGIC LEGEND

- Ledger Dolomite
- Conestoga Limestone
- Elbrook Formation (Limestone)

Figure 10
Sites, Well Yield and Geology

Other formations in the study area can be expected to yield usable quantities of water. However, the fewer potential contamination sites, the lack of large excavated openings and the absence

of deeply weathered layers with enlarged secondary openings make these formations less sensitive to contamination.

In conclusion, the combination of aerial photographic analysis with existing hydrogeologic data indicates that a large number of potential groundwater contamination sites are located in the area of carbonate aquifers and that these aquifers are particularly susceptible to contamination. Furthermore, contamination of these aquifers is particularly significant because they are fully utilized as public water supplies.

CONCLUSIONS

Since completion of the studies described in this report, EPIC has undertaken other projects incorporating hydrogeologic information. These studies have all involved the reproduction of existing hydrogeological information on overlays to photographic enlargements or maps. It is hoped that this type of data presentation will augment the usefulness of both the hydrogeological information and the aerial photographic analysis. The usefulness of incorporating hydrogeologic information with information gathered from aerial photography lies in the ability to locate and describe historical waste sites and show their relationship to the area hydrogeology. These efforts are not meant to replace technical field investigations of hazardous waste sites, but are meant to aid in the initial evaluation of potential groundwater pollution sources.

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DOWNTOWN CARCINOGENS—A GASLIGHT LEGACY

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Red Bank, New Jersey

INTRODUCTION

Gas lights bring back memories of old-world charm and bygone days. The source of gas to power lights was so-called town gas manufacturered by a coal carbonization process during which by-products were formed: coke, tar and ammonical liquor. The by-product tar is the source of current concerns.

In many areas where gas or coal tar were manufactured, the tar was stored in tanks or dumped into pits. Unfortunately, extensive soil and water contamination has occurred through spillage and leakage. Much of the coal tar and oils were used as a source of chemicals, to oil roads, as extenders for asphalt, as creosote to impregnate wood and as fuel. Thus, these tars can be found in widespread areas.

However, the major problem appears to be at the former sites of the coal gas or tar plants where high concentrations of residues may still be present as trapped pools of oil and tar or spread out over considerable areas, contaminating soils as well as underground and surface waters. The major contaminants are polyaromatic hydrocarbons (PAHs), many of them carcinogenic, phenolic compounds, heavy metals and cyanides. These materials constitute serious health problems.

More than 1100 sites have been identified in the United States,[1] and only a few have been examined in detail. Even fewer have been treated to reduce or eliminate the potential hazards. The vast majority of the former sites have not been properly located, cleaned up or tested to determine the extent and nature of contamination; nor are there plans to do so. In this paper the author describes the history, gives examples of the specific problems and makes recommendations for generalized actions which need to be taken at former coal gas and tar sites. The seriousness of this problem could dwarf many of the currently designated Superfund sites in magnitude, since most sites are in downtown areas; they have not been properly located and contain toxic materials. These sites constitute serious health hazards to an unsuspecting population.

BACKGROUND

Before the availability of natural gas, the major source of combustible gas was coal. Following the lead of Great Britain, city coal gasification plants were built in the United States: Baltimore in 1816; Boston in 1822; and New York in 1825.[1] By 1920, there were 1,114 gas plants in the country.

Gas was manufactured by heating coal white-hot and pouring water or oil over it to produce gas, tar and other products. The gas was piped to the community to be used for illumination, heat and industrial purposes.

Some plants maximized production of coke and tar. Thus, there were three types of plants based on slightly different variations, i.e., coke, gas and tar plants. All plants produced tar as a major product or by-product, and this chemical is the prime concern of this paper.

Prior to 1887, when tar distillation was established as a separate industry in Philadelphia, it can be assumed the tar produced was largely disposed of at or near the plant site as a matter of convenience. The tar generated in the various plants was placed in tanks or on the ground in pits or other locations. Because of these disposal practices and the toxicity of coal tars, many of these sites present serious environmental hazards.[2-9] One site in Burlington, Vermont, appeared on the USEPA's list of 115 priority Superfund sites; subsequently, several others have been included on the expanded list of 418 priority Superfund sites. However, the vast majority of these sites have not been given adequate attention. Those that have been dealt with have generally been discovered due to the appearance of a problem. To illustrate this, brief histories of several well-known locations follow.

Stroudsburg, Pennsylvania

As a consequence of Hurricane Diane in 1955, Brodhead Creek experienced its greatest flood. Subsequently, the Army Corps of Engineers modified the stream channel between 1958 and 1960. By 1980, this new stream bed was undercut about 6 ft; to strengthen the levees that had been built, some additional digging was performed. In the course of this work, coal tar was identified in open trenches along the shore of this creek. An investigation determined that a coal gasification site had operated in this area for nearly 100 years prior to 1939.

Approximately 10,000 gal of oil were found in underground pools at the site, and extensive soil contamination was found between the plant and the creek, a distance of about 375 ft. Analyses of the residual oil showed 15 Polynuclear Aromatic Hydrocarbons (PAH), some of them known carcinogens i.e., Benzo (a) pyrene, at concentrations ranging from 0.10% to 3.6%. Low concentrations of phenolic materials were also found, but this is not unexpected due to the extensive leaching of these water-soluble components since 1939. High concentrations of metals such as Al (218 mg/l), Fe (460 mg/l) and Mn (25.5 mg/l) plus cyanides (0.30 mg/l) were detected in shallow groundwater.

This site received Superfund monies. It has been cleaned up, a 700 ft bentonite-cement slurry cut-off wall has been constructed to prevent further movement of pollutants into the stream and monitoring wells are in place.

Ames, Iowa[3]

Since 1927, aromatic hydrocarbons in $\mu g/l$ concentrations have caused taste and odor problems in the aquifer supplying Ames, Iowa. This contamination has forced the abandonment of five city wells close to the source and partial use of other wells. The source of contamination, a gas plant waste pit abandoned in the late 1920s, was identified in 1961 and removed to the sanitary landfill. However, problems with water quality continued, and in 1975 an over-

flow channel (which flowed from the waste pit) was located as the primary source of contamination.

Tests showed the presence of 15 major classes of organic compounds typical of coal tar residues in municipal wells. Aromatic hydrocarbon contamination was found in the sand and gravel deposits which form the "buried channel aquifer" from which Ames obtains its water. Movement of coal tar residues from the original pit and surrounding areas was traced and proved by extensive drilling, excavation and test work.

After thorough study of the problems and potential solutions, a pumping trough barrier was built to pump out the contaminated areas over the next 3-5 years. By that time, it is hoped the soil will have leached sufficiently to reduce the level of contaminants to acceptable levels. In addition, limited pumping of wells has been initiated and new wells have been drilled away from the contaminated area.

Plattsburgh, New York[4]

From 1896 to 1960, a coal gasification plant operating along the Saranac River in Plattsburgh deposited coal tar in unlined ponds at this 11 acre site. Since 1960, periodic release of coal tar into the river has been observed. Over the years, the coal tar ponds were filled with various materials including ash, cinders and miscellaneous soils.

Soil to a depth of 13 ft (to fill or bedrock) beneath the original ponds contains coal tar components. The heavier-than-water compounds in coal tar formed a separate phase and moved along the impermeable till through sand and gravel to the river. Discharges of coal tar into the river were sporadic and occurred mainly in the summer. The soil contained an average of 1.5% coal tar with concentrations ranging up to 9.6% at some locations. Detailed analyses of the hydrocarbons were not conducted but may be presumed to contain carcinogenic PAHs. High concentrations of heavy metals and phenols were also found.

Models were developed to study movement of coal tar with time to aid in remedial actions. To prevent further contamination of the river, soil along the river bank was excavated, a cofferdam built and uncontaminated soil filled in behind the structure. To prevent further flow into the river from inland areas, a cement bentonite wall was constructed through the clean fill adjacent to the river bank. A 735 ft soil bentonite wall was built around the main coal tar pond site and spoils area, covered with a 36 mil Hypalon liner, sand, topsoil and then seeded. Monitoring wells have been placed at critical sites and land use restrictions mandated by the New York State Department of Environmental Conservation.

St. Louis Park, Minnesota[5,6,7]

Even prior to the closing in 1972 of a coal gasification plant that operated for about 50 years, state and local agencies had been concerned about water quality in St. Louis Park, Minnesota. Based on soil and water tests over an area of several square miles, and at depths to 700 ft, seven municipal water wells have been closed and several others threatened. Twelve PAHs identified as carcinogens by the USEPA were found in water and soil samples. Concentrations in the aquifers tested ranged from 30-200 μg/l for known carcinogens; other PAHs were found at levels of 200-3,000 μg/l. The USEPA's *Ambient Water Quality Criteria for Polynuclear Aromatic Hydrocarbons*, published in October 1980, recommends zero as the allowable level.

For the purposes of the St. Louis Park studies, the following criteria were established: (1) for individual PAH identified as carcinogens, the assumed criteria was 2.8 μg/l (or the detection limit, if higher) and (2) for other individual PAH, the assumed criteria was 28 μg/l (or the detection limit, if higher). These criteria were applied to potable water and ambient groundwater.

The extensive contamination of soil (much of it peat with a high adsorbent capacity for organics) and aquifers could potentially cause high concentrations of PAH for many years to come. Corrective measures proposed, such as treatment with activated carbon, have not been totally adequate. Since the USEPA and other agencies have not determined acceptable levels for PAH, if there are any in potable water, the problems at St. Louis Park remain unresolved. Control of pumping rates and drilling of new wells in uncontaminated areas are among current considerations.

Ft. Lewis, Washington[8]

In December 1979, the U.S. Department of Energy reported a spill of about 2,300 gal of SRC liquid during transfer of the liquid from a storage tank to sample drums.[8] To prevent possible contamination of ground, surface and drinking water, a large volume of soil was removed from the spill area. Soil to a maximum depth of 20 ft was removed and replaced with clean material. The land surface was sealed and wells were installed to pump off contaminated water and for long-term monitoring of the area. Analyses of the oil spilled showed it to be a fuel oil blend, 2.1:1, Middle Distillate: Heavy Distillate. Detailed analyses are provided in the report[8] and may be summarized as follows:

	Found by Extraction (%)	Found by GC-MS (%)
Aromatic & Aliphatic Compounds	82	52
Phenolic Compounds	11	5.4
Basic Compounds	6.9	2.3
TOTAL	99.9	59.7

Approximately a dozen Priority Pollutants were found in the SRC fluid by GC-MS analysis. They were: naphthalene, acenaphthene, fluorene, fluoranthene, phenanthrene/anthracene, pyrene, chrysene/benzo (a), anthracene, benzol (b + k), benzo (a + c)-pyrene and phenol.

These materials were carried off in the removed soil and placed in a secure landfill area. The remedial actions taken in this SRC fluid spill have apparently localized groundwater contamination and prevented intrusion into drinking water supplies.

CURRENT CRISES— NEW JERSEY AS AN EXAMPLE

Pollutants from over 1,100 former coal processing sites throughout the country still present potential serious hazards to our health and environment. New Jersey (one of the most densely populated states, with expanding industry and residential areas) has done more to identify and resolve this problem than any other state. And yet, with nearly 60 sites identified (Table 1) by the Department of Environmental Protection,[10] only one has been fully tested. On about half of the sites, coal tar residues have been identified; the remainder have had little or no testing. The exact location of several sites is not known. The most completely tested site is at Belmar Township in Monmouth County.

BELMAR, N.J. GASIFICATION PLANT SITE

In August 1982, an oily discharge was discovered at a marina in the nearby Shark River.[11] Investigations traced the source of oily discharge to the catch basin system for the Borough recreational park and garage.

It was determined that this site had been used for about 50 years as a coal gasification plant. In 1952, it had been sold by Jersey Central Power & Light Co. (JCPL) to New Jersey Natural Gas Co. (NJNG). In 1971, all equipment, tanks and buildings at the site were dismantled and NJNG deeded the site to the Borough in 1976. Subsequently, the Borough built a recreational park on this land. During construction, the Borough hauled in approximately 1 to 5 ft of fill material to cover the rubble located on the site and installed three catch basins along the northern site boundary to improve drainage.

In August 1983, samples from the soil borings and a nearby stream were taken at the Belmar site and analyzed (Table 2). Only the base neutrals were separated for analysis. These results showed

Table 1
Identified Coal Gasification Plants in the State of New Jersey

A. South Jersey Gas Company*
1. Atlantic City—Kirkman Boulevard
2. Atlantic City—Florida, Georgia and Sunset Avenues
3. Pleasantville—Franklin Avenue
4. Egg Harbor—Atlantic and Buffalo Avenues
5. Hammonton—Twelfth Avenue
6. Bridgeton—Vine and Water Streets
7. Millville—North Second Street
8. Glassboro—Union and Grove Streets
9. Paulsboro—Jefferson Street, east of Billingsport Road
10. Swedesboro—Auburn Road and Bridgeport Road
11. Penns Grove—Pitman Street and the railroad tracks
12. Salem—Fifth and Howell Streets

*Present owners of former coal gasification plant

B. New Jersey Natural Gas Company/Jersey Central Power & Light
1. Dover in Morris County—Carrol Street
2. Belmar—16th and railroad
3. Cape May City—Lafayette and St. John Streets
4. Ocean City—11th and West (Atlantic City Electric)
5. Long Branch—Long Branch Avenue and Brook Street
6. Lakewood—Clover Street and Laurel Avenue
7. Toms River—Water Street
8. Wildwood—West Garfield and Lincoln Avenue
9. Asbury Park—Prospect and Sewell
10. Atlantic Highlands—W. Lincoln, Garfield and West Avenues
11. Boonton

C. Elizabethtown Gas
1. Elizabeth—Erie Street between Third and Florida
2. Elizabeth—South Street and Center Street
3. Perth Amboy—Margaret Street
4. Rahway—intersection of Central, Hamilton, Irving
5. Flemington—E. Main Street
6. Newton—Driller Avenue
7. Lambertville—S. Main at Ferry Street†

8. Washington Boro (Warren)—S. Lincoln at railroad tracks†
9. Newton—E. Clinton Avenue†
10. Phillipsburg—Railroad tracks at Reese Court†

†Site located in the service territory of Elizabethtown Gas, but never owned or operated by the company.

D. Public Service Electric & Gas
1. Hobart Avenue Gas Works—Hobart and Oak Street, Bayonne
2. Camden Gas Plant—Front and Spruce Streets, Camden
3. Camden Coke Plant—Front and Delaware River, Camden
4. Gloucester Gas Works—Jersey Avenue and Sixth Street, Gloucester
5. Hackensack Gas Works—Hudson and Water Streets, Hackensack
6. Harrison Gas Plant—4th Street and Passaic Avenue, Harrison
7. Hoboken Gas Works—13th and Clinton Streets, Hoboken
8. Halladay Street Works—Halladay Street, Jersey City
9. Old Provost Street Works—6th and Provost Streets, Jersey City
10. West End Gas Plant—St. Pauls and Duffield Avenues, Jersey City
11. Mount Holly Works—W. Washington Street, Mount Holly
12. Front Street Works—McCarter Hwy. and Passaic River, Newark
13. New Brunswick Works—Catherine and Somerset Streets, New Brunswick
14. Paterson Gas Plant—E. 5th and Leon Streets, Paterson
15. Plainfield Gas Works—E. 4th and Washington Streets, Plainfield
16. Central Gas Plant—Raritan River and Silver Lake Avenue, Edison Twp.
17. Ridgewood Gas Works—Ackerman Avenue and Bellair Road, Ridgewood
18. Riverton Works—Main Street, Riverton
19. South Amboy Gas Works—George and Feltus Streets, South Amboy
20. Trenton Gas Plant—Brunswick Avenue, Trenton
21. Trenton Gas—365 South Warren Street, Trenton
22. Woodbury Works—WFSSRR and Woodbury Creek, Woodbury

E. Other Sites
1. Kearney—Koopers Coke
2. Tuckahoe
3. West Paterson—Memorial Drive‡
4. Hawthorne—Route 208 North‡
5. Hawthorne—Wagaraw Road‡

‡Disposal sites

Table 2
Data from Belmar Site of Coal Gasification Plant

	8/3/83	8/3/83	8/3/83	8/3/83	8/3/83
Date of Sample					
Sample Number	C83-62	C83-64	C83-63	C83-65	
Compu/Chem Number	10134	10136	10135	10137	
Location	Stream Sediment by Park, Boring #4, About 300 ft West of Abandoned Tank	On Site Soil Boring #1, at Base of Abandoned Tank	On Site Soil Boring #3, About 100 ft NW of Abandoned Tank	On Site Soil Boring #2, About 100 ft East of Abandoned Tank	On Site Soil Borings
Base Neutrals					
Units	ug/kg	ug/kg	ug/kg	ug/kg	ppm
Acenaphthene	4000	BDL (2)	BDL (3)	BDL (1)	BDL-0.37
Acenaphthylene	6800	300000	1500	5600	" 0.04
Anthracene	6400	140000	BDL	BDL	
Benzo(a)Anthracene	11000	110000	1100	BDL	
Benzo(a)Pyrene	9200	140000	1100	BDL	0.01-8.9
3,4 Benzofluoranthene	13000	85000	1700	BDL)	0.01-4.6
Benzo(k)fluoranthene	13000	85000	1700	BDL)	
Bis(2-Ethylhexyl)phthalate	6800	BDL	BDL	BDL	BDL-0.07
Chrysene	11000	100000	1000	BDL	
Bluoranthene	16000	170000	1400	BDL	0.02-3.7
Fluorene	6000	260000	BDL	4400	BDL-0.09
Phenanthrene	24000	580000	520	9200	
Pyrene	23000	240000	1700	5200	0.02-9.7
Naphthalene	BDL (1)	1300000	300	29000	0.02
Benzo(GHI)Perylene	BDL	BDL	640	BDL	BDL-4.6
Indeno(1,2,3-cd)Pyrene	BDL	BDL	760	BDL	BDL-3.2
Anthracene/Phenanthrene	-	-	-	-	BDL-0.73
Benzo(a)Anthracene/chrysene	-	-	-	-	0.02-5.7
Diethylphthalate	-	-	-	-	BDL-0.02
Dimethylphthalate	-		-	-	BDL-0.17
Di-n-butylphthalate	-	-	-	-	BDL-0.39

BDL = Below Detection Limit
(1) = 4000 ug/kg
(2) = 50,000 ug/kg
(3) = 200 ug/kg

Date of Sample	3/1/83	3/1/83	3/1/83	3/1/83
Sample Number	20056	20058	20059	20057
Sample Location	Soil Sample @ 5'3", 20 ft. East of Oil Storage Tank on Site	Soil Sample @ 4'2", 60 ft. West of Oil Storage Tank on Site	Inlet to Sump Pump Pit in Basement	Soil Sample @ 4'10", 30 ft. South of Oil Storage Tank on Site
Base Neutrals, ppm				
Acenaphthene	3.3	913	19	
Acenaphthylene	3.3	870	12	
Anthracene/phenanthrene	23.9	1333	34	14.9
Benzo (b,k) fluoranthrene	3.3	1130	5	8
Benzo (a) pyrene	4.3	1406	6	6.9
Butyl benzylphthalate	-	-	-	109
Benzo (g,h,i) perylene	3.3	-	4.4	8
Bis (2-ethylhexyl) phthalate	-	-	66	149
Chrysene	4.9	1648	8	10.3
Dibenzo (a,h) anthracene	3.8	-	-	-
Di-n-butylphthalate	16.3	-	8	236
Diethylphthalate	6.0	-	-	-
Dimethylphthalate	8.7	-	-	40
2,4 Dinitrotoluene	6.5	-	-	
2,6 Dinitrotoluene	28.2	-	-	
Fluoranthane	2.7	493	7	4.6
Fluorene	3.8	449	15	-
Indeno-(1,2,3-c,d) pyrene	6.0	-	4.8	4.6
Naphthalene	2.2	-	29	-
Pyrene	6.0	681	20	2.9
Volatile Organics				
Methylene Chloride	150	-	-	145
Benzene	-	-	140	-
Toluene	-	500	2	-
M-Xylene	-	505	13	-

the presence of a number of hydrocarbons typical of coal tar residue. Significant concentrations of known carcinogens and priority pollutants were found. Considerable variations were noted depending upon sampling location, with the highest concentrations generally found at the base of the abandoned tank. Very high concentrations of carcinogenic and priority pollutants were also found in the stream bed sediment. This would seem to indicate a buildup had occurred over a period of years, caused by a flow from the site.

Based on the data obtained to date, there is significant cause for concern due to the presence of known carcinogens. The site has been closed down and fenced off to prevent access. The full extent of soil and water contamination is not known, but more testing and monitoring are currently underway by JCPL.

Adjacent to the Belmar site is a clothing factory which has had a flow of oil into a basement sump for a number of years. Soils and liquid from the sump have been tested (Table 3). Again, only base neutral extracts were examined. These data also show a wide range of organic compounds, among which are carcinogens and priority pollutants. Due to the location of an on-site fuel storage tank, these data do not show adequate proof that the coal gasification site is the sole source contributing to this problem. However, it is a good possibility, and further analyses of collected oils and testing at additional sites are needed.

MAGNITUDE OF THE PROBLEMS IN THE UNITED STATES

Throughout the country, relatively little work has been done on former coal gasification sites. As noted, there were 1,114 operating coal gasification sites in 1920. Based on the New Jersey experience, this number could be low by as much as 50% of the final total of plants, since the industry peaked in the 1940-50 era. (1920 data showed 36 sites in New Jersey; recent studies located almost 60 sites.)

Inquiries have been made to all USEPA Regions, state environmental agencies and a number of gas companies. Responses from 29 states, the USEPA and two gas companies have identified 40 known sites outside the 60 found in New Jersey. Thus, over 90%

of the former sites are unknown to the USEPA and state environmental agencies.

On most of the sites investigated to date, serious health and environmental hazards have been found, and it may be anticipated that the large number of unknown sites still present similar hazards to an unsuspecting public. The major problems are to locate these sites, assess the hazards and take remedial actions. These are discussed below.

No. of States Contacted	Nature of Responses	No. of Sites Located	No. of Sites Reported in 1920 by USGS in These States
50	10 positive	100*	437*
	19 negative	0	437†

*Includes 60 in New Jersey
†Identical numbers are coincidental

Discovery of Former Coal Gasification Sites

Of the six examples cited earlier, most were discovered by accident. Few governmental agencies have made attempts to look into this problem for two major reasons: (1) these sites are not readily apparent and records showing their existence are difficult to obtain; and (2) most states do not classify coal gasification residues as hazardous wastes and thus have not established this as a high priority concern.

Inquiries made to 50 state environmental agencies have not produced the desired results:

Thus, even in the ten states which have initiated studies, all but New Jersey have found less than 10% of those reported by USGS. The reason for this is probably that the data are not easy to find. A review of the USEPA's ERRIS lists can provide leads, but the most complete data resides with the gas companies. Even they have to do considerable searching to find the sites. According to the USGS data, there were 960 companies producing gas from 1,114 plants in 1920; almost every plant was separately owned. The current gas

companies often inherited these operations. Over the years, most plants were dismantled and the properties (often in what are now prime downtown areas) were used for other purposes or sold. Attempts to obtain data from gas companies have met with mixed results, generally unsuccessful. However, in order to fully resolve this problem, cooperation from the gas companies is essential.

Potential Health and Environmental Hazards

Evidence presented herein and elsewhere has shown that coal gasification residues do present serious health and environmental hazards. These problems need to be resolved. Extensive work has been done in England[12, 13] to identify and solve similar problems of soil and water pollution. To adequately identify and overcome these problems, consideration needs to be given to the following hazards:

- Intrusion of carcinogens, PAH, phenols, heavy metals and cyanides into aquifers and water supplies must be controlled to acceptable levels to protect our water supply
- Skin contact with soil containing coal gasification residue may result in irritations and possible carcinomas
- Ingestion and inhalation
- Uptake of contaminants in food plants with heavy metals being a major concern
- High concentrations of aromatic and unsaturated organics as well as heavy metals can inhibit or prevent plant growth
- Chemicals may attack building materials and services. Hydrocarbons can migrate through plastic pipe and cable coverings as well as joint sealing compounds, possibly causing deterioration of these materials. Acidic phenols and heavy metals can accelerate corrosion of metals and concrete. Liquid residues are known to penetrate cement and cinderblock walls.
- Both surface and underground fires and explosions are possible in areas of pooled oil and tar residues. Careless ignition sources or underground short-circuits are several possible means of starting fires.

It has been reported[14] that epidemiological studies in Kentucky have shown high incidence of skin cancer among people in contact with soil from a former coal gasification site. In Pennsylvania, buildings and grounds of an abandoned site are being used as a Nursery School.[15] These sites have not been investigated and cleaned up. How many more potentially hazardous sites are being used improperly? Answers are needed as well as elimination of the hazards.

RECOMMENDED ACTIONS

The nation's approach to existing coal gasification sites has varied from well-planned at St. Louis Park, Minn. to an emergency response at Stroudsburg, Pa. There needs to be a better, more deliberate approach.

The mere presence of contamination may be taken as proof that a hazard exists. When investigating these sites, a balance must be sought between the legitimate concerns for public health and environmental safety and the need to bring land back into an appropriate and productive use.

A recommended method to deal with these serious problems at former sites containing coal tar residues follows:

Phase I—Discovery and Evaluation
- Location of all sites
- Collection of historical information
- Description of current and planned activities at each site
- Preliminary description of geology and hydrology
- Evaluation of potential hazards and urgency for remedial action based upon current and planned usage

Phase II—Testing and Remedial Design
- Detailed testing and evaluation to determine the extent and nature of contaminants in the soil, aquifers and nearby waters
- Install monitoring wells to measure movement of contaminants with time
- Establish the potential hazards and identify options for remedial actions
- Set criteria for allowable concentrations of various contaminants in soil, aquifers and water

- Select the optimum scheme for remedial action at each site which will meet the established criteria, consistent with current and planned usage

Phase III—Cleanup and Monitoring
- Implement the selected remedial actions
- Establish specific site use restrictions which should be mandated by law
- Provide for long-range monitoring to assure that corrective actions continue to meet specified criteria and also that site restrictions are not violated

CONCLUSIONS

Many of the sites which remain to be evaluated will pose serious enough hazards to health and the environment to rate them above many on the current Superfund lists. Coal tar residues contain known carcinogens and priority pollutants. Governmental agencies need to take immediate action to deal with these sites in the most expeditious manner to prevent further serious damage to people and the environment.

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AN UNDERGROUND TANK SPILL RISK ASSESSMENT PROGRAM

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INTRODUCTION

In this paper, the authors suggest a methodology by which one can rapidly and inexpensively assess potential risks from unprotected underground steel tanks and use this information to implement a cost-effective program of risk reduction. This method is particularly useful when the budget for investigation is limited and funds must be allocated carefully. In this case, the immediate problem is to identify those tanks which should be investigated in detail. One wishes to concentrate the investigation budget on those tanks which potentially present the greatest risks and avoid investigating those tanks which present little or no risk.

The authors propose using a screening procedure which evaluates each tank on the basis of inexpensive and readily available information. For a relatively small cost, a company can identify those tanks with high, intermediate and low risks. It can then allocate the budget for detailed investigations to those tanks posing the highest risk.

How Large is the Problem?

There is mounting evidence that a major source of groundwater contamination in the United States is from leaking underground storage tanks containing fuel oils, gasoline, various solvents and other toxic materials. Recent estimates put the total number of installed tanks at about two million. Studies have indicated that up to 20% of these tanks may be leaking. Assuming a leak rate of only 1 gal/day/tank, tens of millions of gallons per year of toxic materials could be discharging into the environment. These numbers indicate why leaking underground tanks are rapidly becoming a major pollution control issue receiving high priority attention by the USEPA, the states and local governments. Thirty-three states have underground tank regulations either on the books or under legislative consideration.

Why Evaluate Tank Risk?

Many firms that use significant numbers of unprotected underground steel tanks are at risk. A tank spill at a facility can involve a number of potential problems. The spill, if it has migrated off-site, can result in injury or damages to persons or property. The tank regulatory environment is changing almost daily, and continued regulatory compliance requires frequent communications with regulatory agencies. Litigation and site remediation costs can be high. Media coverage in these instances can have a detrimental effect on business. Political and civic involvement could be extensive as well.

Therefore, there is a strong impetus to be knowledgeable about the present risks and act early to reduce the risks where practicable.

GENERAL APPROACH

Implementation

A spill risk assessment program must be an ongoing effort with periodic review of all tanks. In any one period (e.g., fiscal year), there are three steps that one should take:
- Screen the tanks to determine which will be investigated this period
- Investigate those tanks, identifying those needing replacement and/or site remediation
- Carry out the appropriate actions

The last two steps should be planned individually for each tank or site, depending on its particular circumstance. The first step is discussed in this paper. That initial phase gets the process started by quickly surveying all the tanks and their respective environments. Since all tanks are included, the process must use a uniform approach to all tanks. Also, since all tanks are included, it must be relatively inexpensive. For a company with several hundred tanks, even spending $1,000 per tank would be prohibited for this initial screening phase. Consequently, the screening procedure must be based on relatively inexpensive and easily obtained information.

During each period, the process is repeated and the tanks/sites having the highest risks are identified and dealt with, thus substantially lowering their risks. The risks presented by the entire population of tanks eventually will be reduced and controlled at reasonable levels.

Risk Defined

The word "risk" has several commonly used technical and colloquial definitions. In the context of this paper, risk can be described as the probability of an event occurring that is associated with an adverse consequence during a stated period of time. An adverse consequence is one that produces harm to a human population or damage to the environment. The risk level or severity is dependent upon the event probability and the magnitude of the adverse consequence.

Risk assessment, then, is the general term for the study of decisions subject to uncertain consequences. Risk estimation is the calculation of risk level, and risk evaluation is the process of determining the significance of the estimated risks and planning actions to deal with those risks.

The two components of risk, the potential for adverse consequences and the likelihood of an initiating event, can be shown in the form of a matrix (Fig. 1). The upper right corner of the matrix represents a situation involving a high probability for occurrence of an initiating event (e.g., a tank leak) combined with a high poten-
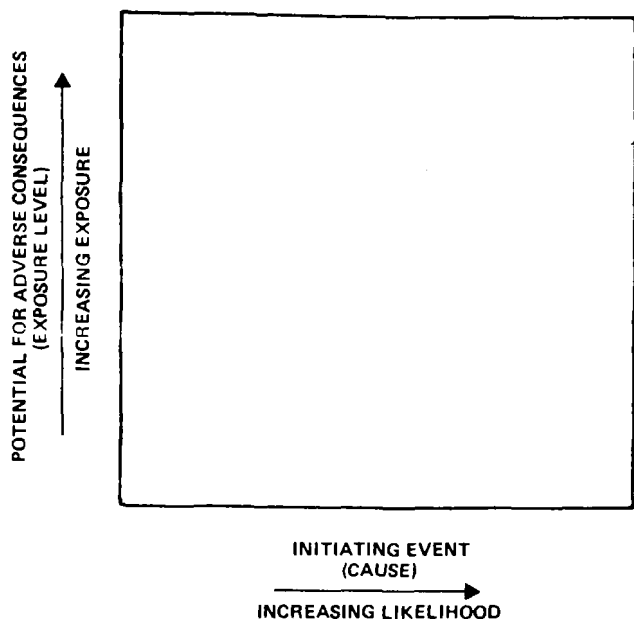
Figure 1
Components of Risk

tial for adverse consequences (e.g., a large population exposed) resulting in high risk level. The opposite corner of the matrix represents low risk level.

Underground Tank Spill Risk

The risk associated with underground tanks can be expressed in terms of the matrix shown in Figure 2. In this figure, the potential adverse consequence is environmental or public health hazard and the initiating event is a tank leak. Situations where tank leakage probability is low and the potential environmental hazard is also low have an acceptable risk; no action is needed at this time. However, the risk is unacceptable where tank leakage probability and potential environmental or public health hazard are high and some action is needed to reduce the overall risk. Risk with regard to underground storage tanks, then, can be expressed as the combination of tank leak probability and the potential for environmental or public health hazard.
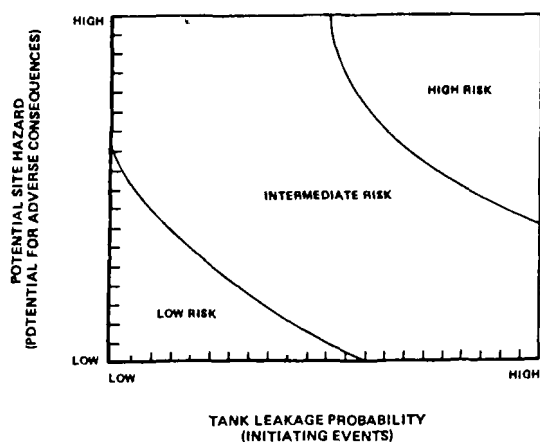
Figure 2
Underground Tank Risk Matrix

LEAK RISK ESTIMATION

A method is required to provide an estimate of future risk of tank leakage. Tank tightness testing will only provide information on the condition of a tank at the time of the test. Computation of the Soil Aggressiveness Value (SAV), a numerical procedure that relies on basic soil characteristics such as pH, moisture, resistivity and sulphides, and tank age can explain only a small porportion of data variability.

In an attempt to develop a better predictive tool for underground tank leaks, the American Petroleum Institute (API) engaged one of the authors to perform a statistical analysis of the occurrence of corrosion failures in unprotected underground tanks and to develop a mathematical model of the process which leads to tank failure.

The first step consisted of data collection from API member companies. The result of this survey was a chart showing the frequency of leaks by tank age (Fig. 3). Leaks were reported as early as 2 years after installation and as late as 45 years. Thus, it was clear that tank age was a very poor predictor of tank failure.

An unprotected steel tank installed in clean backfill without impurities and not subject to abrasion during installation will experience external corrosion which is essentially uniform over its surface. Such a tank will, for all practical purposes, last the useful life of the accompanying facility. Previous studies have shown that approximately 23% of all installations corrode evenly.

In the remaining 77% of the tanks observed, one or more localized anodes were established on the tank surface during installations. Typically, these anodes consisted of impurities in the backfill material, abrasion of mill scale, failure to remove shoring, etc. Under these conditions, the corrosion leading to perforation proceeds at a pace determined by the chemical and physical characteristics of the backfill. The relevant variables governing electrochemical reaction in the tank environment are electrical resistivity of the soil, pH (acidity), moisture content, sulphide content of the soil and size of tank.

The approach taken in the study was based on the hypothesis that, in the presence of electrochemical corrosion, age to leak should be proportional to the probability that a leak has started, while 30% had a high leak risk—greater than 78% (Fig. 4). What the profile will look like in 2 years if no leak detection program is implemented is shown in Figure 5. At that time, 41% of the tanks will have a high leak probability.
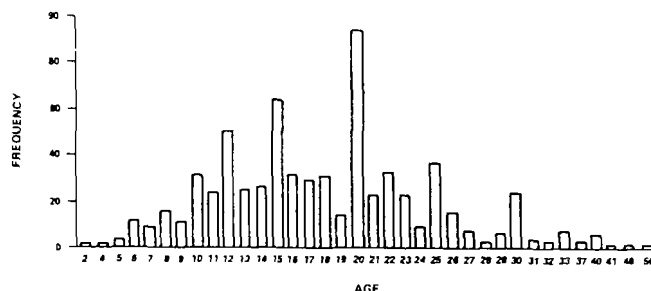
Figure 3
Tank Age to Leak

An example of a cumulative probability distribution over the age at which a leak begins calculated from the mean age relation presented earlier is shown in Figure 6. Based upon the soil characteristics of this sample, the mean age to leak is about 12 years. A similar plot for a soil sample taken from a different facility is found in Figure 7. In this case, the mean age to leak is 23 years. Thus, soil conditions can have a significant impact on the expected life of a tank.

The soil corrosion test data can be used to determine if a tank is uniformly corroding by employing a tank tightness test on the high part of the probability curve. One test will reduce the probability of leaking from its maximum of 77% (note that 23% of all tanks corrode evenly and will not leak) down to 50%. A second tightness test a year later will reduce the probability to 20%, and a third test will reduce the probability of point corrosion to a negligible 1%.

In summary, the soil corrosion test is a quick, reliable and cost-effective technique for estimating the risk of tank leakage. Using this technique, one can determine the probability that the tank will begin to leak before the end of the coming period (i.e., before the next cycle of evaluation and investigation begins).

vertically into the water table and then travels horizontally to some point of contact without being detected and removed or contained. The point of contact could be a water well, a body of surface water, a basement or utility conduit. The number of people affected will depend upon the population density in the adjacent area.

Thus, the site hazard evaluation function is basically a product of two terms: the first term is a surrogate for the probability that the leak would reach a point of contact undetected, and the second term is the population density. It is assumed that the surrogate for the probability that the leak reaches a point of contact undetected be cased on the time it would take to migrate to the nearest point of contact (i.e., sensitive receptor). The calculation of this time is

Figure 4
Company Profile
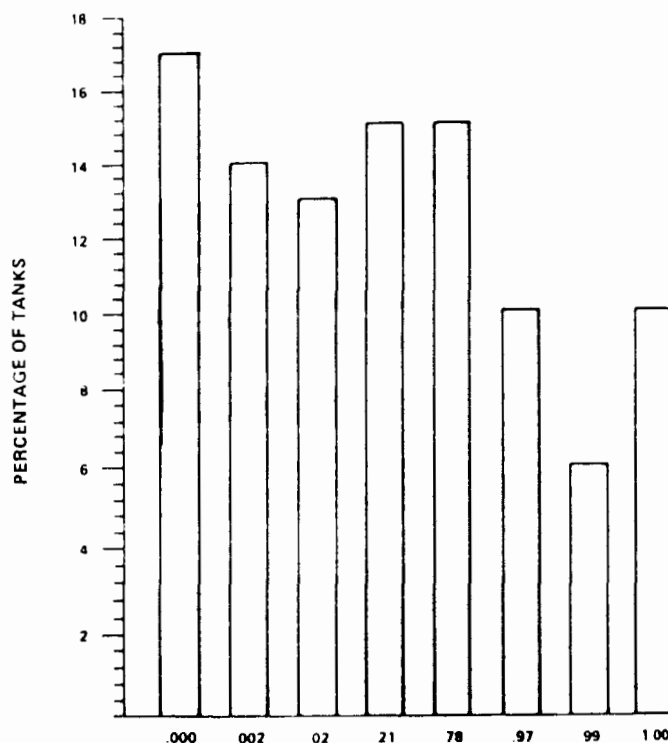
Figure 5
Company Profile Probability of Leak Two Years from Now

SITE HAZARD ESTIMATION

The hazard of a given site makes up the second component of risk—the potential for adverse consequences. Site hazard, in turn, has two elements: (1) environmental hazard and (2) public health hazard.

Environmental hazards include aquatic habitat impairment, contamination of productive wetlands and loss of habitat. Public health hazards include contamination of surface and groundwater supplies used for drinking water, inhalation of gases or fumes that have migrated through the soil to confined areas such as basements and explosion hazards from those fumes.

The site hazard evaluation methodology described below relies on easily obtainable information and is, therefore, quickly and inexpensively implemented.

Since it is not feasible to do a complete risk analysis for each tank at this stage, the authors use an evaluation function that is a surrogate for the expected number of people affected by a leak, given that a leak occurs. It is a surrogate in the sense that it includes the major factors that describe the risk and should be strongly correlated to the expected risk that would be determined by a rigorous and thorough analysis.

With respect to public health hazard, it is assumed that the public will only be affected by a leak in a tank if the material first seeps

based upon the vertical distance to the water table and the horizontal distance to the nearest point of contact.

The time for the material to migrate vertically to a water table can be computed as a function of the depth to the water table, the permeability of the soil and the net precipitation. The time to migrate horizontally to the nearest point of contact is simply a function of the distance.

Finally, these times must be converted into a surrogate for the chance that the leak will actually reach the nearest point of contact undetected. If the time were short (i.e., one month), the chance would be very large, with a probability near unity. If the time were long (i.e., 24 months), the chance would be low. It is likely that the leak would be detected. This leads to a function shaped like that shown in Figure 8.

The form of the site hazard evaluation function is:

$$R = C(T_v + T_h) \times P \qquad (1)$$

where:

T_v = Vertical time of travel to a water table

T_h = Horizontal time of travel to nearest point of contact

P = Population density within a given radius of the tank(s)

$C(time)$ = as defined in Figure 8
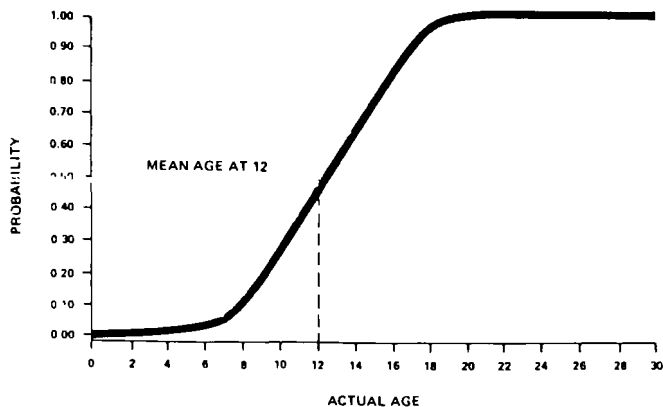
Figure 6
Cumulative Distribution Over Tank Age at First Leak
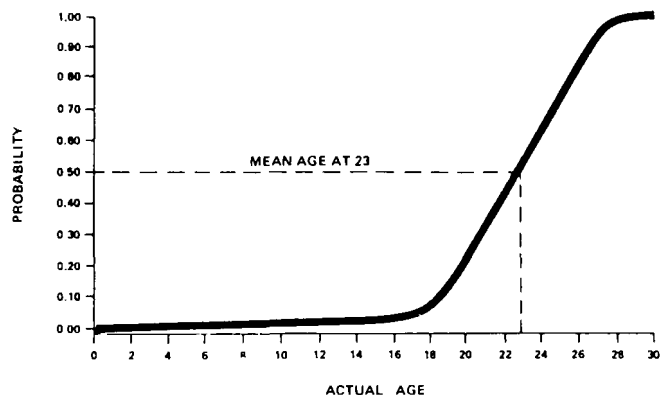
Figure 7
Cumulative Distribution Over Tank Age at First Leak

RISK EVALUATION

Once the tank leak probability and site risks have been evaluated, they are multiplied to give the overall risk. It is also instructive to plot each tank on a figure such as Figure 2, showing tank leak probability on one axis and site risk on the other.

At this point, there is an urge to define what regions of the matrix represent acceptable versus unacceptable risks in economic terms. However, since the level of acceptable risk is greatly depen-
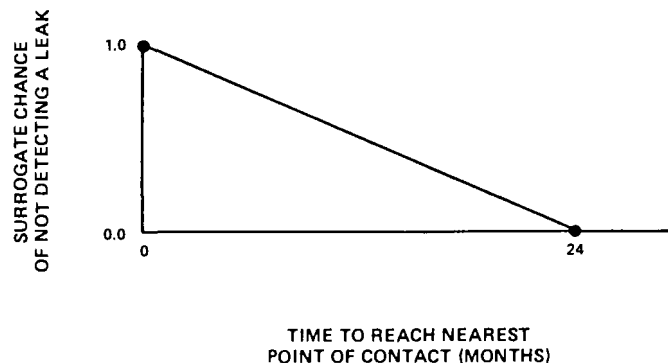
Figure 8
Probability of Leak Detection

dent upon the risk attitudes of the decision maker, judgments on acceptability cannot be made quantitatively. In comparing the risks to the benefits derived, a weighting factor is necessary to take into account risk perception when translating the risk into economic terms.

One can conveniently divide the risks shown in Figure 2 into three broad zones. The facilities with clear problems, such as a high tank leak probability and/or high potential environmental or public health hazard, fall into the highest risk category. Facilities with low tank leak probability and corresponding low potential site hazards fall into the lowest risk category. All other facilities then fall into the intermediate category (facilities for which insufficient information is known for category selection also go into the intermediate level).

This procedure provides two useful results. First, it gives a priority ranking of the tanks. This priority can be used to identify tanks/sites to be investigated during the coming period. The tanks posing the greatest total risk should be investigated first, up to the budget limitation for tank investigations in this period. The second useful result is some insight into the source of the risk for each tank. When the tank is plotted in Figure 2, one can see not only how high the risk is, but also whether it is due to risks of a leak in the tank or due to high expected consequences given there is a leak. This information is essential for planning the next stage of investigation on the tanks.

Because of the potentially high investigation, cleanup and litigation costs associated with some underground tank spills, it is felt that the value of the information obtained in the risk assessment procedure described here justifies the expense of investigation and repairs. Taking the long view of the underground tank problem will result in better resource allocation and lower costs overall.

DETECTION OF GROUNDWATER CONTAMINATION BY SHALLOW SOIL GAS SAMPLING IN THE VADOSE ZONE THEORY AND APPLICATIONS

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INTRODUCTION

Groundwater contamination by volatile organic compounds is a widespread problem resulting from the disposal and spillage of solvents used in a wide variety of industrial processes. Several of these chemicals, particularly the halogenated organics, have action limits set at levels significantly less than 100 $\mu g/l$. These limits have been, or are now being, established by state and federal regulatory agencies (Table 1). For example, an action level of 5 and 10 $\mu g/l$ for trichloroethylene (TCE) has been used as a guideline for requiring aquifer restoration in California. Similar limits are being used in Arizona.

To date, the discovery and definition of the areal extent of volatile organics in groundwater has relied upon the installation and sampling of borings and monitoring wells. While samples from such installations provide the best method to quantitatively measure the presence or absence of volatiles in groundwater, they have the following disadvantages:

- They are expensive to install, develop and sample
- The level of contamination is not generally known until after the well has been installed, developed and sampled and the results returned from the chemical laboratory
- Many wells are often required to adequately define the extent of the plume to evaluate potential aquifer restoration methods

In this paper, the authors present theory and field data that demonstrate the applicability of soil gas sampling and measurement of volatile compounds as a method of detecting the presence of these volatile compounds in groundwater. The method can provide a cost-effective means to supplement data collected by conventional means.

Table 1
Some Common Solvents and Associated Compounds that have been Detected in the Groundwater

Compound	Formula	Vapor Pressure MMHg @ 20-25 °C	Boiling Point °C	Aqueous Solubility	Specific Gravity	Limits for Long Term Exposure EPA NAS $\mu g/l$	Proposed New Enforceable(1) Standards	Priority Pollutant
carbon tetrachloride	CCl_4	99	77	No	1.58	0.4 4.5	*	x
chlorobenzene	C_6H_5Cl		133	No	1.10	72		x
p-dichlorobenzene	$C_6H_4Cl_2$		174	No	1.45			x
1,2,4 trichlorobenzene	$C_6H_3Cl_3$		213	No	1.46			x
ethyl benzene	$C_6H_5C_2H_5$		136	Slight	0.87			x
1,1 dichloroethane	CH_3CHCl_2		58	Slight	1.17			x
1,2 dichloroethane	$ClCH_2CH_2Cl$		83	No	1.26	.71 .95	*	x
1,1,1 trichloroethane	CH_3CCl_3		75	No	1.32	3800 1000	*	x
1,1,2 trichloroethane	$CHCl_2CH_2Cl$	17	114	No	1.44			x
1,1,2,2 tetrachloroethane	$Cl_2C:CCl_2$		121	No	1.62			x
chloroethane	C_2H_5Cl		12	No	0.92			x
trichloromethane	$CHCl_3$		61.	Slight	1.48	0.10 (2)		x
dichloromethane	$ClCH_2Cl$		40	Slight	1.33	150 -		x
chloromethane	CH_3Cl		-24	Slight	0.92	-		x
dichloro difluoromethane	CCl_2F_2		-30	No		1600 -		x
trichloro fluoromethane	CCl_3F		24		1.49	- -		x
trichloroethylene	$CHCl:CCl_2$		87	Slight	1.46	2.8 4.5	*	x
chloroethylene	$CH_2:CHCl$	2300	-14	Slight	0.91	1-2 -	*	x
1,1 dichloroethylene	$CCH:CHCl$		48	Slight	1.20	70 -		-
tetrachloroethylene	$CCl_2:CCl_2$		121	No	1.62	0.9	*	
acetone	CH_3COCH_3		56	Yes	0.79			-
isopropyl alcohol	$CH_3H_5CH_3$	33	82	Yes	0.79			-
toluene	$C_6H_5CH_3$		111	No	0.87	- 340		x
xylenes	$C_6H_4(CH_3)_2$		135	No	0.86	- 670		-
cyclohexanone	$C_6H_{10}O$	136	156	Slight	0.95			-
methyl ethyl ketone	$CH_3COC_2H_5$		80	Yes	0.80			-

Data Sources: Chemical Rubber Company Handbook of Chemistry and Physics, USEPA Multimedia Environmental Goals for Environmental Assessment, Hawley, 1981.
(1) USEPA Region 9, personal communication, *indicates compound for which standards are proposed.   (2) As total trihalomethanes

PREVIOUS STUDIES

Gas phase transport through porous media has been described by numerous investigators. Penman,[4] cited by Glauccum and others,[3] described the movement of acetone and carbon disulfide. Albertsen,[1] in Swallow et al.,[11] measured changes in the carbon dioxide content of soil gas and used these as indicators of metabolic activity over a plume of biodegradable pollutants in an underlying aquifer. Weeks et al.[14] used the downward migration of two atmospheric fluorocarbons (CCl_3 F, [Freon-11] and CCl_2 F_2, [Freon-12]) through a thick vadose zone to evaluate the parameters describing such movement as a diffusive process. Diffusion of fluorocarbons through the unsaturated zone was measured by Thompson and Kraemer[12] in an investigation of gaseous diffusion potential relative to low level radioactive waste disposal.

Recently, Glauccum et al.[3] used shallow soil gas measurements of benzene to define a contamination plume containing both volatile organics and electrically conductive compounds in a shallow aquifer. Soil gas measurements were made with a portable organic vapor analyzer (OVA) and were all above the 1.0 ppm detection range of that instrument.

Swallow and Gschwend[11] obtained data from a controlled laboratory experiment to show that trichloroethylene moves upward from the water table into the capillary fringe as shown in Figure 1. They also presented data indicating measurable soil gas concentrations of benzene, toluene and TCE from depths of 25 and 50 cm above the water table found at a depth of about 120 cm.

In a recent theoretical study, Jury et al.[6] described the mechanisms responsible for the movement of both liquid and volatile organic pesticides through the vadose zone.

To the authors' knowledge, field data demonstrates measurable quantities of volatile compounds in soil gases found above contaminated aquifers at depths greater than a few meters.
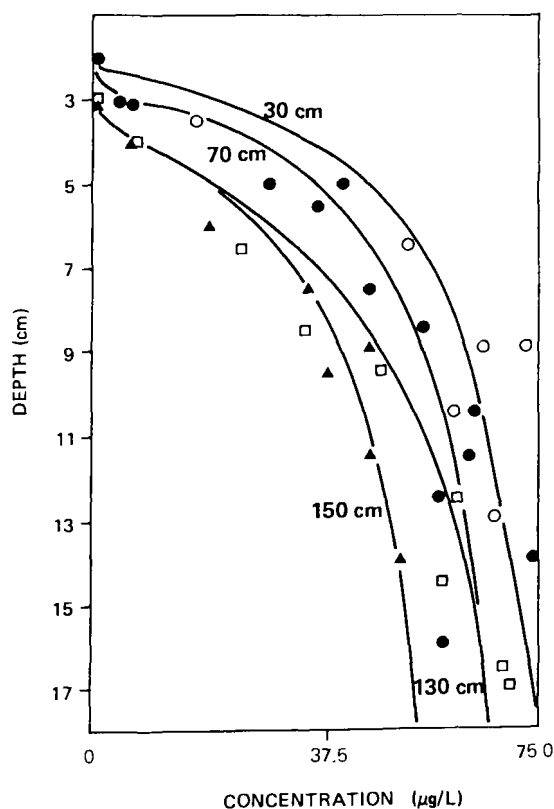
THEORY

For volatile organics present in groundwater to be detected in the vadose zone, they must move upward from the saturated zone through the capillary fringe and then to the point from which the soil gas samples are taken. In this section, the mechanisms by which such movement occurs are discussed. This discussion shows that water table fluctuations enhance and in some cases may be required to provide significant upward movement of volatile contaminants. The relationship of the saturated zone, capillary fringe and vadose zone and the dominant transport mechanisms in each are shown in Figure 2.
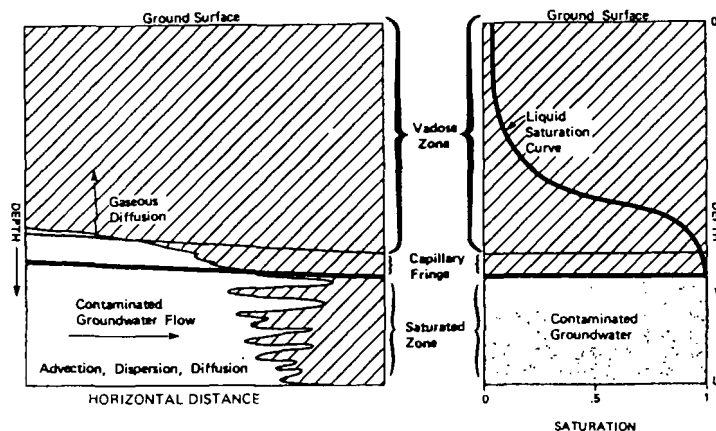
Figure 2
Schematic Illustration of the Mechanisms Responsible for Contaminant Transport in and above a Contaminated Aquifer, and the Relationship Between Liquid Saturation and Depth for an Equilibrium Profile

Neither retardation of volatile organics by adsorption on soils nor biodegradation are considered in this paper. For the volatile compounds measured during this study, these mechanisms are considered less significant than those that will be discussed.[8]

Transport in Saturated Sediments

Transport of contaminants through the zone that is fully saturated with liquid and in which the liquid is under positive hydrostatic pressure occurs by advection, hydrodynamic dispersion and molecular diffusion.

Advection, or transport with moving groundwater at the mean groundwater velocity, is usually the dominant transport mechanism in the saturated zone. For relatively coarse-grained aquifers, in the absence of significant recharge or groundwater extraction, such transport is usually predominantly horizontal. Advective flux in any dimension is described by Darcy's law corrected for porosity: V = (K/N_e) ΔH, where K is the hydraulic conductivity tensor, N_e is the effective porosity, ΔH is the gradient of hydraulic head and Δ is the interstitial groundwater velocity. The advective flux of a contaminant at concentration C is given by Q_a = VC.

Hydrodynamic dispersion describes transport caused by variations in the hydraulic conductivity of the porous media in directions parallel and transverse to the direction of mean groundwater flow. Dispersion is commonly expressed as a linear function of velocity in the direction of flow: D_x = α_xV, where D_x is the dispersion coefficient in direction x, V is the mean groundwater velocity and α_x is a characteristic length or dispersivity in direction x. Dispersive flux of a contaminant is described by the product of a dispersion coefficient and the concentration gradient as Q_d = Dx_i^∂ $C/\partial x_i$.

Swallow and Gschwend[11] attribute the vertical movement of volatile organic solutes above a uniformly contaminated aquifer to the vertical component of transverse hydrodynamic dispersion associated with horizontal groundwater flow. Transverse hydrodynamic dispersion probably accounts for significant vertical movement only when significant vertical flow components in the

Figure 1
Trichloroethylene Concentration vs. Depth
(from Swallow and Gschwend[11])

small scale velocity field are present in an aquifer. Transverse dispersivities are typically one-half to two orders of magnitude less than the longitudinal coefficients.

Crane and Gardner showed in 1961 that for a uniform sandstone the ratio between the transverse and longitudinal dispersion coefficients ranges from 0.10 at velocities less than 0.01 m/day to less than 0.01 at velocities of 10 m/day. For the horizontal flow experiment in a uniform sand conducted by Swallow and Gschwend,[11] a vertical transverse characteristic length or dispersivity of 0.0033 m was reported. Groundwater velocities were not given in this study to enable computation of the dispersion coefficients.

When flow is predominantly horizontal, a commonly found field situation, vertical transverse dispersion may be less significant than found in the laboratory study of Swallow and Gschwend. Under field conditions, water table fluctuations may provide a more plausible mechanism for transport of contaminants through the capillary fringe and into the vadose zone.

Molecular diffusion describes transport caused by a spatial gradient of the concentration of a solute and is given by a generalized Fick's first law: $Q_d = N_e D_b \partial C / \partial x_i$, where D_b is the bulk liquid diffusion coefficient and N_e is the effective porosity. As described in subsequent sections, diffusive flux through saturated zones is generally small compared to other mechanisms.

Liquid-solid partitioning, or adsorption, is important for some solutes. However, the adsorption or retardation potential for the volatile compounds under conditions of full water saturation is low and is not considered further.

Transport in the Capillary Fringe

By the definition used in this paper, the capillary fringe is that zone above the water table which is fully saturated with water but in which the liquid water is held under negative pressure or tension. This zone, also referred to by some authors as the tension saturated zone, is illustrated in Figure 2. With a number of discrete pore sizes present, the thickness of this zone is equivalent to the pressure head required to empty the largest pores. This pressure head is also referred to by some authors as the air entry or bubbling pressure[2]. Since natural sediments typically have areally varying pore size distributions, the top of the capillary fringe may not be a planar surface as depicted in Figure 1.

Under steady flow conditions, transport through the capillary fringe may occur by the same mechanisms as described for the saturated zone. If the water table does not fluctuate and the flow of contaminated groundwater is predominantly horizontal, the only mechanisms by which contaminants can move across the capillary fringe are transverse hydrodynamic dispersion and molecular diffusion. For commonly encountered horizontal groundwater velocities (0.05 to 2 m/day), the vertical flux due to transverse hydrodynamic dispersion is proportional to the transverse dispersion coefficient. This coefficient is of the order of 1×10^{-3} m²/day for a velocity of 0.1 m/day and α_T of 0.01 m. Diffusive flux is proportional to the liquid diffusion coefficient which is of the order of 1×10^{-5} m²/day. Consequently, contaminant flux rates through the capillary fringe caused by these two mechanisms would be very slow for all but materials having a very high transverse dispersion coefficient caused by anomalous vertical heterogeneities in the aquifer materials.

A fluctuating water table above a contaminated aquifer may provide a more rapid mechanism by which volatile organics may move into the vadose zone. Figure 3 shows a simple case of a water table rising rapidly from position (1) to position (2). This rise pushes uncontaminated water in the capillary fringe upward into the vadose zone. When the water table falls, as shown in position (3), contaminated water will be retained in the vadose zone and throughout the capillary fringe. Hysteresis in the relationship between pressure head and water content enhances the retention of contaminated water in the vadose zone under these conditions of water table fluctuation. This enhancement occurs because, at a given tension, more water is retained in the pores as the water table is lowered than enters the pores as the water table rises. This hysteresis in the
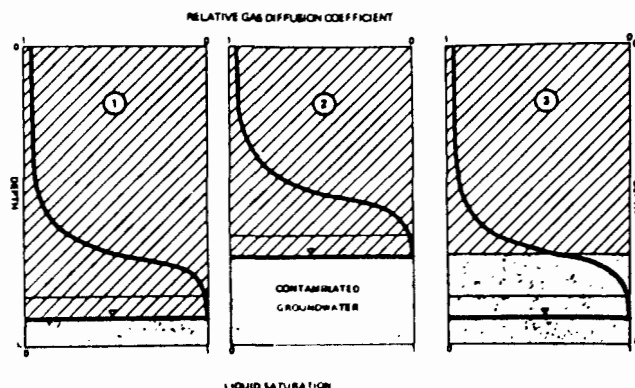
Figure 3
Schematic Illustration Showing Contamination of the Vadose Zone and Capillary Fringe by a Rising (2) then Falling (3) Water Table

pressure head-water content relationship is usually more pronounced for coarse-grained soils near saturation than for fine-grained soils (Hillel, 1971).

Transport in the Vadose Zone

The presence of volatile contaminants in and above the capillary fringe provides the opportunity for their upward transport at rates several orders of magnitude greater than those under conditions of full saturation.

Under conditions of no significant recharge and no redistribution of soil moisture, the two dominant mechanisms of transport in the vadose zone are gas-liquid partitioning and gaseous diffusion.

Contaminant flux caused by gaseous diffusion is described by Fick's first law applied to a gas filled pore space: $Q_g = D_g \partial C_a / \partial z$, with $D_g = \theta_a \tau D_{ab}$, where θ_a = the air filled pore space, t = tortuosity and D_{ab} = the diffusion coefficient of gas a into gas b. It is assumed that the "a" is the volatile contaminant, and that "b" is the soil gas.

The gas phase diffusion coefficient is about 10^4 to 10^5 times as large as the liquid phase diffusion coefficient.[6,14] Weeks et al.[14] computed gas phase diffusion coefficients for the fluorocarbons CCl_3F and CCl_2F_2 of 0.78 and 0.86 m²/day based on an empirical equation developed by Slattery and Bird.[19] The equation used by Weeks et al. is reproduced here because few measured values for D_{ab} are available in the literature for many of the compounds given in Table 1.

$$D_{ab} = A/P \ (P_a \ P_b)^{1/3} \ (T_a \ T_b)^{5/12} \ [1/M_a + 1/M_b]^{1/2} \ [T/(T_a \ T_b)]^B \quad (1)$$

where P_a, P_b = critical pressure for gases a and b, in atmosphere; T_a, T_b = critical temperatures for gases a and b, degrees K; p = ambient atmospheric pressure, atmospheres; M_a, M_b = molecular weight of gases a and b in g/mole; $A = 2.745 \times 10^{-4}$; $B = 1.823$; T = ambient temperature, in degrees K.

Jury et al. give empirical equations for the gas phase diffusion coefficient through a porous media:

$$D_g = (\theta_a^{10/3}/N_e^2) D_{ab} \quad (2)$$

and for the liquid diffusion coefficient:

$$D_L = (\theta_w^{10/3}/N_e^2) D_c \quad (3)$$

These authors concluded that both the aqueous and gas self-diffusion coefficients (D_c and D_{ab}) were relatively constant at the values of 4.3×10^{-5} and 0.43 m²/day, respectively, for intermediate weight molecular compounds such as most pesticides.

As shown in Figure 3 and in Equation 2, the gas diffusion coefficient is directly proportional to the air-filled porosity. Hence the opportunity for upward diffusion increases as drier soils are found

closer to the land surface under conditions of insignificant recharge and redistribution of soil moisture.

Gas liquid partitioning. Once volatile contaminants are present above the capillary fringe, they will tend to partition between the liquid and gas phases. Measured partitioning coefficients for several volatile organics detected in field samples during one of the authors' studies are shown in Table 2.

The larger the value of K_w, the more volatile the compound and the larger the tendency to be present in the gas phase and to be available for transport by gaseous diffusion in the vadose zone.

FIELD METHODOLOGY

The authors have made measurements of soil gas concentrations of volatile organics at 14 sites in a variety of geologic and climatic environments during the past 18 months. The field methodology developed and used at these sites is presented in this section.

Soil gas samples are obtained from shallow depths by driving a hollow, perforated metal probe to the desired depth. Vertical profiles to depths of less than 3 m are determined by driving and sampling to successive depths. Vertical profiles deeper than 3 m are obtained by driving the soil gas sampling probe ahead of the bottom of a hollow-stem auger that has been advanced to just above the desired sampling depth. Soil gas is pumped from the sampling location at a rate of 2 to 3 l/min by a peristaltic pump. The soil gas sample is collected in a glass syringe by insertion of a clean needle into the sample line. The gas sample is then directly injected into the gas chromatograph in the field.

Table 2
Gas-Liquid Partitioning Coefficients for Some Common Volatile Compounds

K_w = concentration in air/concentration in water

Compound	K_w
F-11	0.7
F-12	0.3
F-113	0.25
$CH_2 Cl_2$	0.37
TCA	0.5
TCE	0.33
PCE	0.43

Soil gas and water concentrations of the volatile organic compounds discussed in this section were made in the field using a Varian gas chromatograph equipped with electron capture (EC) and photoionization (PI) detectors. The procedure incorporates proprietary methodology that enables chromatographic separation of the aliphatic compounds reported in this study in less than 5 min. The separation of the aromatic compounds is usually accomplished in less than 10 min. Detection limits are between 0.001 and 0.01 μg/l for gas samples and between 0.1 and 1.0 μg/l for water samples. All samples are replicated, and reported results are the arithmetic mean of at least 2 replicates.

Table 3
Summary of Field Studies of Groundwater Contamination Using Soil Gas Sampling and Analysis by HLA and TRC

Site Location or Description	Depth to Ground Water	Moisture Content of Vadose Zone	Clays in Vadose Zone?	Volatile Organics Detected
California State Superfund Site	25	moderate	yes	Freon-113, TCE, TCA, PCE
South Valley CERCLA Site Albuquerque, NM	15	moderate to wet	yes	Benzene, TCE, Toluene, TCA
Federal CERCLA Site, Tucson, Arizona	100	dry to moderate	yes	TCE, TCA, PCE, CC13H
Electronics Firm, Southwestern U.S.	80	dry	no	TCE, TCA
County Landfills, Arizona	100	dry to moderate	yes	TCA, TCE, PCE
New Electronics Plant, Northern California	60	moderate	no	none
Aerospace Plant, Northern California CERCLA Site	50	dry	no	TCA, TCE, DCA DCE
Electronics Firm, Northern California	20	moderate to wet	yes	TCE, Freon-113
Chemical Storage and Transfer Facility, Calif.	10	moderate to wet	yes	TCA, TCE, DCE, PCE, Benzene, Toluene
Service Station, Northern California	25	moderate	yes	Benzene, Toluene

Many of the studies have included the sampling of water from existing monitoring wells and analyzing the water samples in the field with the methodology described above. Water samples are all taken with standard sampling protocols for volatile organic compounds. Duplicates of water samples are sent to independent, certified laboratories for quality control testing.

Field quality control for gas sampling involves the following:
•Flushing of the sampling probe, tubing and pump by drawing atmospheric air through the system until concentrations of the compounds of interest are at atmospheric levels as determined by periodic samples of the ambient atmosphere at the site
•Frequent analysis of blanks and known standards in the field

APPLICATIONS

To date, Harding Lawson Associates and Tracer Research Corporation have used the soil gas method to detect and define plumes of volatile organic contaminants in groundwater at 14 sites. These sites have provided a data base for evaluating the applicability and limitations of the method under a wide range of subsurface conditions. All field studies have been conducted where the vadose zone comprises non-indurated sediments. The types of sites and subsurface conditions at 10 of these sites are given in Table 3. This section describes the results of studies at three of these sites in more detail.

California State Superfund Site, Northern California

This site was chosen to verify the method because several plumes of volatile organics have been delineated by the installation and sampling of monitoring wells. A series of aquifers at the site ranges in depth from a few to several hundred meters and consists primarily of fine sands to coarse sands and gravels. The zones between the aquifers are typically clays to silty clays. Elevated levels of Freon-113, 1,1,1-trichloroethane (TCA), TCE and other volatile organics have been found in the shallow aquifer. This contamination resulted from leaks of underground tanks and pipes used for the storage and transmission of these solvents. The following sampling activities were conducted at this site:
•A vertical profile over an area where the shallow aquifer was known to be uncontaminated
•Two vertical profiles over areas where the shallow aquifer was known to be contaminated
•A horizontal transect across a plume that had been well defined by monitoring wells
•An areal survey to determine the extent of volatile compounds in the shallow aquifer
At all of these sites, the water table was between 25 and 33 ft (7.5 to 10.5 m) below the land surface.

Vertical profile over an uncontaminated aquifer. This site was located up-gradient of a known source of contamination. The depth of water at this site is 24 ft (7.2 m). Table 4 contains the results of the analyses performed for methylene chloride, F-113, TCA, TCE and PCE. The trace levels of the compounds found are lower than the detection level of the laboratory analysis method for

the compounds in water. The trace levels indicated in Table 4 may be due to a lower level of decontamination procedures used for sampling equipment than used for the remaining sites. In contrast to the sites discussed below, no vertical trends or patterns are evident in the data.

Vertical profiles over a known contaminated aquifer. Soil gas profiles were sampled at two sites over a plume of volatile organic compounds that had been mapped using conventional drilling and sampling methods. Data collected at one site are found in Table 5. The increases in concentration of TCA, TCE and PCE with depth at a second site are shown in Figure 4. The data shown in 4a suggest:
•The relative proportion of volatile compounds in the soil gas phase roughly corresponds to predictions based upon the gas liquid partitioning coefficients given in Table 3
•The soil gas concentrations are not in equilibrium with the groundwater as would be predicted based on the partitioning coefficients alone

Data in Table 5 show a similar decrease in concentration with distance above the water table. However, with the exception of TCA, they also show a decrease from the soil gas immediately above the water table to the concentration below the water table. The distribution of compounds at this site is not an obvious function of their aqueous solubility as appears to be the case for the data shown in Figure 4. This may imply separate incidents of the introduction of contaminants into the subsurface.

(a) Vertical Profiles Of Volatile Organics Above A Contaminated Aquifer, Santa Clara County, California

(b) Vertical Profiles Of Volatile Organics Above A Contaminated Aquifer, Tucson, Arizona

Abbreviations are:
TCA = 1,1,1 trichloroethane;
PCE = perchloroethylene;
F-11 = trichlorofluoromethane
F-113 = trifluorotrichloroethane
TCE = trichloroethylene
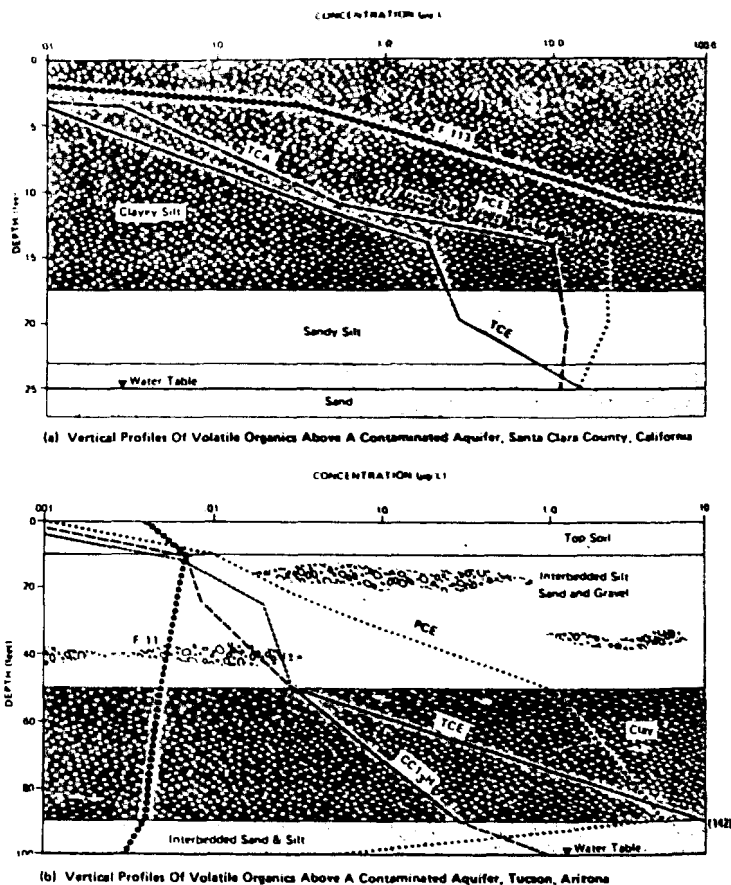
Figure 4
Vertical Profiles of Volatile Organic Concentrations in Soil Gas above Contaminated Aquifers in Tucson, Arizona, and Santa Clara County, California

Table 4
Chemical Data for the Uncontaminated Site
(all concentrations are in μg/l)

Sample	CH2Cl2	F-113	TCA	TCE	PCE
Air above ground (1)	0.1	0.004	0.003	(<0.001)	0.002
Soil gas 10 ft (7.5 m) (1)	0.02	0.04	0.003	0.001	0.05
Soil gas 25 ft (10.5 m) (2)	0.005 ± 0.005	0.09 ± 0.01	0.01 ± 0.01	0.001 ± 0	0.001 ± 0.001
Water (1) (field meas.)	(<1.0)	0.3	0.2	(<0.1)	0.1
Water (ind. lab analysis)			ND	ND	ND

Table 5
Chemical Data for Site 2
(all concentrations are in $\mu g/l$)

Sample	CH2Cl2	F-113	TCA	TCE	PCE
Air above ground (1)	0.1	0.2	(<0.001)	(<0.001)	(<0.001)
Soil gas 5 ft (1.5 m) (4)	1.5 ± 0.8	3.5 ± 0.1	0.14 ± 0.08	0.01 ± 0	0.45 ± 0.2
Soil gas 15 ft (4.5 m) (2)	170 ± 23	71 ± 6	2 ± 1	0.60 ± 0.14	5.0 ± 0
Soil gas 20 ft (6 m) (4)	190 ± 100	100 ± 32	4.0 ± 1.8	0.9 ± 0.1	6 ± 6
Water (1) (field meas.)	29 ± 5	65 ± 13	120 ± 29	0.6 ± 0.3	0.1 ± 0 .1
Water (ind. lab analysis)			70	100	0.50

Transect across a known plume. To evaluate the soil gas sampling and field analysis as the methods for detecting plumes of volatile contaminants, a series of samples was taken and analyzed along a line transect across a known plume of TCE and TCA. The depth to water at this site is 30 ft (9 m). The results of soil gas sampling compared to concentrations found in monitoring wells completed in the shallow aquifer are shown in Figure 5. Soil gases at this site were obtained at depths of from 2½ to 3 ft (0.75 to 0.90 m). The correlation between data obtained by the two methods as shown in Figure 5 is sufficient to use soil gas sampling and analysis as a semi-quantitative technique at this site for detecting groundwater contamination.

Areal survey. Soil gas samples were taken from depths of 2 to 3 ft (0.6 to 0.9 m) in an area where the limits of groundwater containing elevated levels of volatile organics were poorly known. This survey comprised samples taken from 54 soundings as shown on Figure 6. The sampling and field analysis by GC for F-113 was completed in under three days. Concentrations shown on Figure 6 are averages of two replicate measurements.
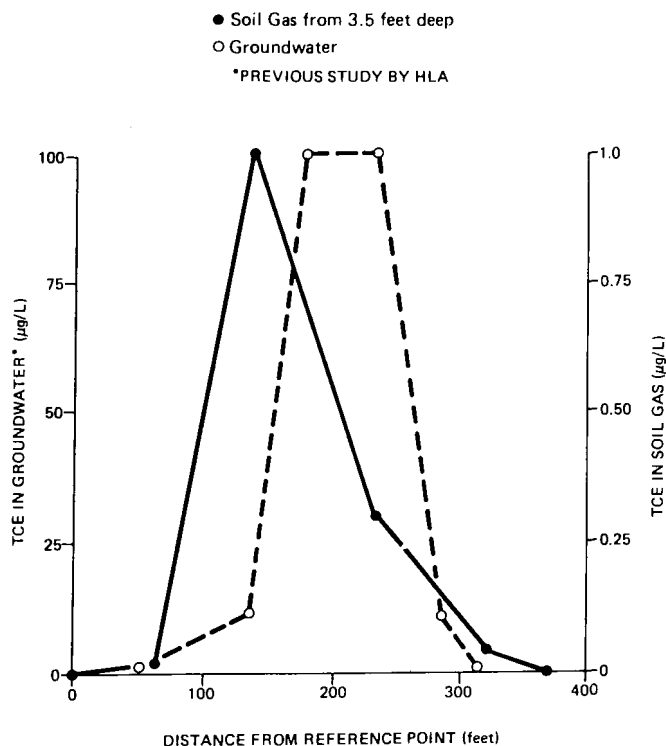
In addition to a rapid survey to define the extent of F-113, this survey was able to delineate a source in the upper part of the study area that was not defined prior to field measurements. The extent of contamination mapped by the soil gas samples was subsequently confirmed by obtaining water samples from borings and wells at several locations as shown on Figure 6. The degree of correlation between volatile organic concentrations in the groundwater and the soil gas is high. The real time field GC analytical capability combined with the rapid means of obtaining soil gas samples resulted in a significant cost savings over conventional drilling and sampling methods.

The subsurface variability of the parameters that control gas phase diffusion is such that a theoretical prediction of concentrations in groundwater from concentrations in soil gas is probably not feasible. However, site-specific calibration of the method can provide at least a semiquantitative prediction of groundwater concentrations. The correlation between soil gas and groundwater concentrations of F-113 at the site of the areal survey is shown in Figure 7. Although scatter exists in the data, the correlation over four orders of magnitude is reasonably good. This correlation can be established by obtaining groundwater samples using conventional means at a limited number of control points.

CERCLA Site, Southern Arizona

This site is characterized by an arid climate. The depth to the shallowest permanent groundwater in the area where the soil gas survey was conducted is approximately 100 ft (30 m). The aquifer at this site is contaminated with TCE, PCE and 1,2 Dichloroethylene (DCE). A vertical profile is reported for this site. The concentrations of PCE, TCE, CCl_{3H} and Freon-11 as a function of depth are shown in Figure 4b. The presence of a 25-ft (7.5 m) thick sequence of clay in the vadose zone is significant. This clay is apparently dry enough or contains sufficient macropores to allow significant upward gaseous diffusion of the compounds found in the groundwater. Upgradient from the area of the survey, the clay serves as a perching layer. Perched conditions were not encountered at the site of the profile.

● Soil Gas from 3.5 feet deep
○ Groundwater
*PREVIOUS STUDY BY HLA

Figure 5
Soil-Gas Transect Across TCE Plume

EXPLANATION

SG-48 ● 10   Soil gas sampling location and F-113 concentration in ug/l

074-4 ◇ 3200   F-113 concentration in groundwater in ug/l
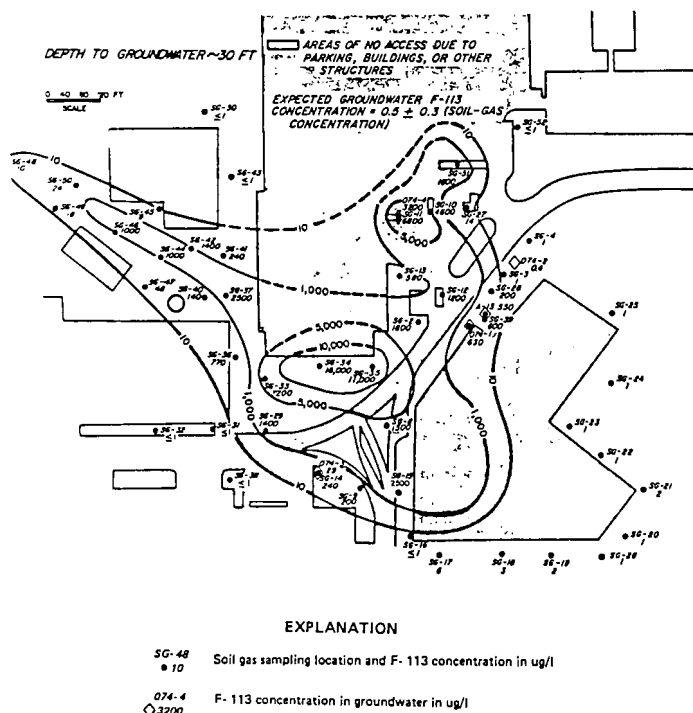
Figure 6
Concentrations of F-113 in Soil Gas Above a Shallow Aquifer, and in Groundwater from the Shallow Aquifer at an Industrial Complex

All compounds found in the soil gas except Freon-11 apparently have their source in the groundwater beneath the site. Freon-11 concentrations show a gradient that indicates a surface or atmospheric source. The data obtained by Weeks et al.[14] showed a similar gradient which was attributed to the downward diffusion of Freon-11 from elevated levels in the atmosphere. Since these elevated levels are present essentially worldwide, it is reasonable to assume that the atmosphere at the site is the source of Freon-11 and that the groundwater is acting as a sink for this compound.

Electronics Manufacturing Plant, Southwestern United States

This site is underlain by groundwater at a depth of about 80 ft (24 m) and is contaminated with TCE, TCA, 1,1 DCE, Methylene Chloride and PCE. The vadose zone at the site comprises fine sands to coarse gravels with little silt and clay. The climate at the site is arid, and the moisture content of the vadose zone is low. This soil gas survey was implemented to evaluate the extent of any off-site contamination to determine if off-site monitoring wells and/or aquifer restoration might be required. Additional detail in the plume configuration was also needed to enable optimal location of on-site extraction wells for aquifer restoration. The study was conducted in two phases:
- A survey of the property boundaries and on-site sources
- An off-site transect perpendicular to the direction of the groundwater flow

Contours of soil gas concentrations of TCE and TCA are compared in Figures 8 and 9 to contours based upon water samples from nine monitoring wells that are screened in the top of the aquifer. The agreement between the general plume patterns mapped by both methods is apparent from these figures. The soil gas survey provided additional detail in areas where no monitoring well data were available. In particular, evidence of suspected upgradient contamination from another suspected source was not found, and the zone having the highest concentrations along the southwestern boundary was delineated.

The extent of off-site groundwater contamination was evaluated by conducting a transect across the plume about 250 m downgradient from the site boundary. Both TCA and TCE are present at significantly lower concentrations than those found on-site (Fig. 10). No wells or borings have been installed to confirm this pattern.

To evaluate the reproducability of the method, repeated sampling was done at five sites on successive days. The second sample was taken from the same depth and within 5 ft (1.5 m) of the first of each set. The results of this repeated sampling comparison are shown in Table 6. Students t test analysis of the paired data shows no significant difference between sample means taken on successive days. The t test was done on the logarithms of the raw data because of the wide range in values. The F-ratio test showed the sample variances to be the same at the 0.001 significance level, justifying the use of the Students t test.

Six of the on-site soil gas samples were taken in the immediate vicinity, within 10 ft (3 m) of existing monitoring wells. Water samples taken from these wells using dedicated Teflon and PVC bladder pumps were analyzed in the field with the same methodology used for the soil gas samples. The correlation between the soil gas and groundwater concentrations is shown in Figure 11. The regression was performed on the common logarithm of the values because of their wide range.

CONCLUSIONS

Theoretical considerations of the mechanisms by which volatiles may reach the shallow sampling depths from contaminated groundwater include the following:
- The principal vertical transport mechanisms under conditions of no recharge or water table fluctuation are: transverse hydrodynamic dispersion through the saturated zone and the capillary fringe, liquid phase diffusion through the capillary fringe and gas phase diffusion through the vadose zone.
- Water table fluctuations coupled with hysteresis in the water content-pressure head relationship can greatly accelerate the introduction of contaminants into the vadose zone. A significant water level rise followed by a decline will be more effective in providing this introduction of contaminants above the capillary fringe than other sequences of water level fluctuations. Water level fluctuations may, in fact, be required in many situations to provide significant gas concentrations at the base of the vadose zone to detect soil gas contaminants at shallow depths.
- The introduction of volatiles into the capillary fringe and the vadose zone by water level fluctuations in a contaminated aquifer may result in a significant degree of subsurface contamination that may impact the time required for aquifer restoration. In some instances, aquifer restoration by groundwater extraction may need to be enhanced by flushing of these zones by artificial recharge as part of the overall remedial action for contaminated aquifers.

Field data obtained in this study demonstrate the following:
- The presence of volatile organic compounds in groundwater may be detected by analyzing soil gas samples from depths as shallow as 1 m for water levels at about 10 m and from as shallow as 3 m for water levels as deep as 30 m.
- Vertical profiling of the concentrations of volatile organics found in soil gases provides a vertical concentration gradient which may be used to infer whether aquifer contamination or a surface source is responsible for the observed concentration profile.
- When field analyses of the volatile compounds are made, the shallow soil gas sampling method conducted along transects can provide a rapid real time assessment of the extent of subsurface contamination. As such, the method may be used to augment conventional drilling and sampling methods to more economically provide additional data on the extent of contamination.

| | Sample Site Pairs | | F-113 Concentrations (µg/l) | |
Site	Groundwater	Soil Gas	Groundwater	Soil Gas
1	074-2	SG-3	14	11
2	A 13	SG 39	580	600
3	74-4	SG-11	8000	6900
4	074 3	SG 14	50	250
5	074-6	SG-47	15	48
6	074-5	SG-44	32	1000
7	074-7	SG-49	34	18
8	B8	SG-32	1	5.2
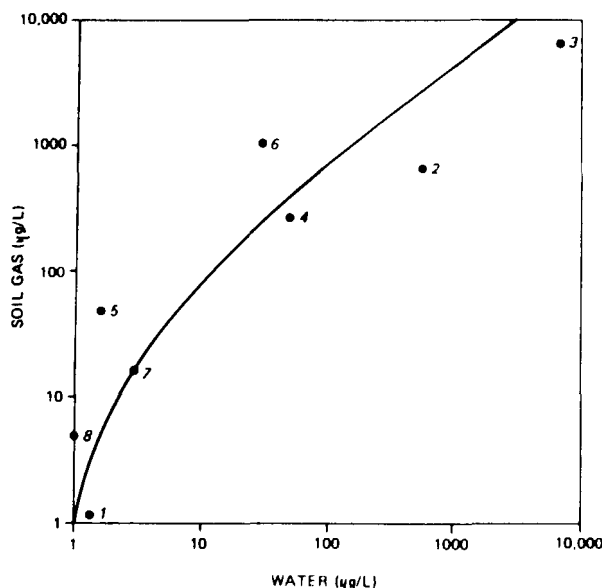
Figure 7
Relationship Between F-113 Concentrations in Soil Gas and Groundwater. Sample Numbers Refer to Sites Shown in Figure 6.

LOG OF TCE IN GROUND WATER

LOG OF TCE IN SOIL GAS

LEGEND

● Monitoring Well

▲ Soil Gas Probe

〰3.1 Log of TCE Concentration in Groundwater

〰3.1 Log of TCE Concentration in Soil Gas

0   100   200 meters

Figure 8
Comparison of TCE Concentration Distribution as Determined by Groundwater and Soil Gas Samples, Southwestern US Study

LOG OF TCA IN GROUND WATER

LOG OF TCA IN SOIL GAS

LEGEND

● Monitoring Well

▲ Soil Gas Probe

〰3.1 Log of TCA Concentration in Groundwater

〰3.1 Log of TCA Concentration in Soil Gas

0   100   200 meters

Figure 9
Comparison of TCA Concentration Distribution as Determined by Groundwater and Soil Gas Samples, Southwestern US study

Figure 10
Transect Down-gradient from Property, Southwestern US Study

Figure 11
Relationship between TCA and TCE Concentrations in Soil Gas and
Groundwater for the Southwestern US Study

Table 6
Results of Repeated Sampling, Southwestern US Study

Sampling Point	TCA 5/8/84	5/9/84	TCE 5/8/84	5/9/84
SG10	1.8	1.9	4.0	4.1
SG100	2.9	3.2	.85	.99
SG110	2.9	2.7	3.6	3.3
SG50	315	200	675	360
SG45	220	172	240	200

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●Because of the approximately exponential decrease in concentrations from the water table to the land surface, soil gas detection limits for volatile organics may need to be less than 0.01 μg/l to detect moderate to low levels of contamination from water tables at depths greater than 10 m.

●At sites where tight, very wet to saturated clays are present, or where the contaminated aquifer lies beneath a clean aquifer, the soil gas method cannot be used effectively to detect groundwater contamination.

QUALITY CONTROL ATTRIBUTES OF PROCESS ANALYTICAL DATA

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INTRODUCTION

The National Contract Laboratory Program (CLP) is a nation-wide network of laboratories under contract to the USEPA. The Program was originally designed to supply routine chemical analysis services to the Hazardous Waste Site Investigation program. These laboratories work under firm, fixed-price controls using standardized analytical methods, sample handling procedures and data reporting protocols.[1] The CLP also has the capability and resources to supply these same analytical services to other programs and agencies.

The CLP provides the USEPA with analytical data on which to base work assessments, to institute remedial action or to initiate enforcement procedures in order to contain or properly dispose of identified hazardous waste. The Program is structured with a strong orientation toward supporting enforcement activities. Protocols and methodologies are USEPA-approved to provide data of documented quality using analytical quality control (QC) procedures and a system of document control.

The primary objective of the CLP is to provide routine, high volume analysis of samples collected from hazardous waste sites. Using a single national program for this effort: (1) ensures that all samples are analyzed according to uniform and consistent protocols which is a vital requirement for enforcement actions, and (2) achieves low analysis costs through the economies of scale. All CLP analyses are performed by private laboratories of proven ability which have won competitive contract awards. Continued high quality laboratory performance is assured through ongoing evaluations conducted by the Environmental Monitoring and Support Laboratory/Las Vegas (EMSL/LV). EMSL is also responsible for developing all methods, standards and protocols used by the contractor laboratories. Final data review and evaluation is conducted by the CLP support staff with assistance from EMSL.

Analytical Methodologies

Standardized analytical protocols are used for all routine work carried out within the CLP activities.[1] In addition to the methods of analysis, the protocols specify the quality control precedures and documentation requirements. A generalized schematic of the analytical protocols is given in Figure 1. The need for uniform and consistent protocols is in juxtaposition to the almost infinite variety of samples that are encountered in the Program.

INTERPRETATION OF DATA QUALITY

The scope of the data requirements is imposed by the various investigation and remedial programs which generate the samples and apply the data to litigation and engineering purposes. Data used in these programs must be known and of documentable quality.

Objectives of Data Evaluation

- Reduce the probability of "bad data" not being identified
- Increase the amount of usable data by resolving technical problems
- Create and use a system of data quality indicators to guide the data users
- Assist in the application of data to particular policy questions given required quality parameters
- Evaluate new methods of analysis in terms of efficacy and applicability
- Evaluate laboratory method performance
- Evaluate the adequacy of methods and laboratories in the determination of new compounds or in new matrices
- Assist in the application of data to particular field problems, given required measurement and performance parameters
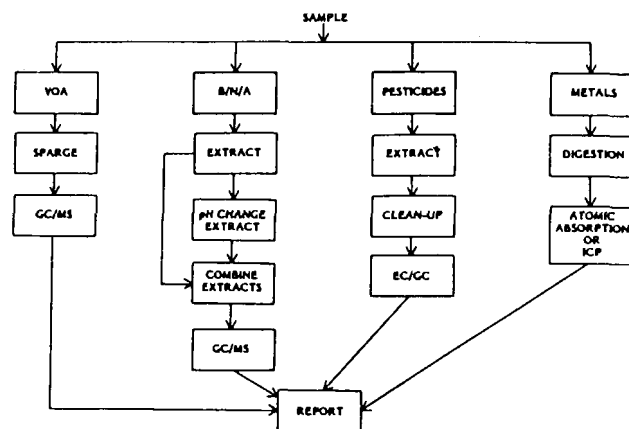
Figure 1
Analytical Protocols

An analytical result, like a tangible product, goes through a manufacturing process. Like a manufactured item, the analytical result has identifiable attributes which can monitor the quality of the result. The evaluation of data quality occurs within the context of the requirements placed upon the data. The estimation of quality is a function of the information content of the data as they apply to their intended use. This conforms more to the classical definition of product quality as the appropriate level of quality for the application or function of the product.

The analytical process may be treated as a semi-continuous production process in which the component processes contributing to the quality of the overall results may be separated. Simple statistical techniques are used.[1] These may be derived from the monitoring, evaluation and qualifications of batch process manufacturing. The evaluation of quality requires knowledge of the behavior of the controlling variables or functions which correlate with those variables in the analytical process.

Precision, accuracy and recovery may be calculated for analytical determinations if some of the following assumptions are incorporated into the model structure supporting these calculations:
- The sample population is homogenous by virtue of the fact that the matrix is in the same category; i.e., all well water or river water.
- Compounds spiked into each sample are spiked at approximately the same level for a particular compound.

Components of Analytical QC

The samples taken from a hazardous waste site are very different from samples taken from industrial processes, clinical/biological sources or nearly every other type of system where sampling is a means of obtaining information. The sample is less uniform with respect to matrix as well as analyte. In spite of these very important differences, adequate statistical procedures can be employed to determine the precision and accuracy of the data and to establish realistic performance limits.

Surrogate Compounds

Standard laboratory analytical quality control procedures[1] are used to monitor variables affecting the analytical process. The analytical QC sample types and the categories of quality attribute data that are derived from these samples are listed in Figure 2. Laboratories also employ special techniques suited to hazardous waste site environmental analysis. These techniques include the use of surrogate compounds spiked into each sample. These procedures help to derive information about the precision and accuracy of the analytical function.

The QC protocols for the analysis of hazardous waste site samples employ isotopically enriched organic compounds as analytical tracers. These compounds are isotopically different from their natural abundance analogues, or they are the fluorinated analogues of chlorinated pollutants. The surrogate compounds, by the analytical fraction which they monitor, are listed in Table 1. The procedure differs from isotope dilution in which an isotope analogue (radioactive or stable) is determined and the results for the analyte are normalized to the recovery of the isotopically enriched analogue.

Surrogate compounds are added to the appropriate analytical fraction to monitor the analytical procedure. Results obtained for the surrogate compounds do not monitor individual compound results except in the instance where the surrogate is an isomer or analogue of a particular analyte. To characterize the analytical data, the percent recovery of the surrogate compound is calculated and normal statistical attributes of the data are calculated. The statistical attributes calculated and the arithmetic formula for each attribute are given in Table 2. These attributes may then be used to quantitatively define the analytical quality of the data derived from samples taken from a particular site and provide a sound analytical basis for the interpretation of the physical phenomena indicated by comparative analysis of these data.

Surrogate compounds have several advantages relative to using the split samples and spiked samples required in each study:
- Each sample contains QC information on accuracy and precision. Statistically valid information can be generated much more rapidly than with the matrix spiked and duplicate samples.
- Surrogates are totally synthetic compounds; i.e., they are not found in the environment and interferences are minimized.
- Surrogates are introduced into each sample at the analyzing laboratory. Analytical results for surrogates are totally independent of field sampling procedures.

Figure 2
QC Sample/Data Attribute Matrix
Darkened boxes indicate QC sample appropriate for the data attribute.

Table 1
Surrogate Analytes

VOLATILE ORGANIC CPDS

bromochloromethane
d_8 - toluene
1-chloro-2-bromopropane
bromofluorobenzene

d_6 - benzene
1,4 - dichlorobutane
d_4 - dichloroethane

BASE/NEUTRAL EXTRACTABLES

d_5 - pyridine
d_8 - naphthalene
2 - fluoroaniline
pentafluorobenzene
2 - fluoronaphthalene

d_5 - nitrobenzene
2 - fluorobiphenyl
d_{10} - pyrene
d_{14} - p - terphenyl

ACID EXTRACTABLES

d_6 - phenol
pentafluorophenol
d_3 - 2,4, - dimethylphenol

2 - fluorophenol
tribromophenol

PESTICIDES

decafluorobiphenyl

dibutylchlorendate

2,3,7,8 - DIBENZO - p - DIOXIN

1,2,3,4 - TCDD

Table 2
Statistical Attributes of Sample Data

WITHIN BATCH PRECISION

$$S_w = \left(\frac{\sum_{i=1}^{L} n_i S_i^2}{N} \right)^{1/2}$$

OTHER DEFINITIONS

L — NUMBER OF ANALYTICAL BATCHES

n_i — NUMBER OF SAMPLES IN THE iTH BATCH

N — TOTAL NUMBER OF SAMPLES

S_i — STANDARD DEVIATION OF THE iTH BATCH AVERAGE RECOVERY, $\bar{X}_i$

BATCH TO BATCH PRECISION

$$S_L = \left(S_{\bar{X}}^2 - \frac{S_w^2}{N_i} \right)^{1/2}$$

WHERE:

$$S_{\bar{X}} = \left(\frac{\sum_{i=1}^{L} (\bar{X}_i - \bar{\bar{X}})^2}{L - 1} \right)^{1/2}$$

N_i — NUMBER OF SAMPLES PER BATCH

$\bar{\bar{X}}$ — GRAND AVERAGE OF ALL BATCHES

STANDARD ERROR OF A SINGLE MEASUREMENT

$$T_1 = \left(S_w^2 + S_L^2 \right)^{1/2}$$

Shewhart QC Charts

Originally developed for control of production processes where large numbers of articles were being manufactured and inspected on a continuous basis, control chart concepts have been readily adapted to laboratory operations where the analyst produces comparatively fewer results on an intermittent basis. Inherent in the approach is the recognition of the basic assumption that combinations of random and systematic variations exist in every method and within every laboratory. The mathematical relationships and facsimile of control charts are shown in Figure 3. Industrial acceptance of control charting and other statistical techniques has grown out of the basic theories and procedures of Shewhart.[2]

Evaluation of Site Data

Data are evaluated on a study-by-study basis. Each study is composed of samples from only one site. The CLP refers to each study as a Case. The general procedure is to: segregate information by analytical batch; check off required information; calculate statistical parameters; and, if enough information is available, calculate control charts based on the data presented. Such charts are meaningful only to the degree that enough information is available to obtain a reasonable representation of the required parameters and that the data included within the information can be assumed to be homogeneous.

PROCEDURES

Segregation of the Analytical Data

The data are related to each other as a consistent sample matrix type; as being produced by a particular laboratory; and as a part of a particular analytical batch. The relationship by matrix and laboratory are self-explanatory. The analytical batch consists of those samples that are processed simultaneously or in a continuous sequence under conditions that associate the samples. Samples processed simultaneously by the same personnel using the same batch of solvents and methodology can be considered an analytical batch.

Data Grouping

Recoveries data for each Case were arranged in the following groups:
- Volatiles
- Base/Neutral
- Acids
- Pesticides

Within each chemical grouping, the data were further subdivided by surrogate compound. The data for each surrogate compound are further subdivided by the combination of matrix and extraction data. Examples of distinct matrices include the following:
- Drinking Water (Finished)
- Well Water
- Surface Water (Standing Bodies)
- Surface Water (Flowing Bodies)
- Surface Water (Leachate and Runoff)
- Air
- Soil
- Sludge
- Drummed Materials

This process allows greater homogeneity of the sample population and identifies the analytical batch.

The hierarchy depicted in Figure 4, matrix 2, ultimately contains two VOA batches, two acid extractable batches and two base/neutral extractable batches. Comparison of analytical performance and results can only be within a particular matrix. Parallel reduction of data can be accomplished on matrices 1 and 3, but the data must not be mixed for calculations.

A matrix of the characteristic data by batch is created. This includes average recovery and standard deviation of the average recovery. The types of summary data calculated for each surrogate compound from the characteristic batch data are included in Table 2. The value of determining important or controlling variables is illustrated by the data set in Figure 5. When these symbolic data are sorted by date, it can be readily seen that a systematic difference occurred for those samples that comprise Batch C. This group of samples was more likely subjected to a systematic deviation than a randomly occurring one. Isolating systematic deviations serves to isolate uncharacteristic data and helps identify operational problems or relationships in the laboratory or in the field.

The summary of data collected from multiple Cases analyzed by the same laboratory for the same matrix over a period of time may be combined to construct a control chart using the relationship and charts in Figure 3. Most single Cases do not have enough chronological history to establish reliable control values. The control chart will become more useful as an information tool as more quality control data are stored.

Results

The batch data and summary data are presented in TAbles 3A and 3B for a Case of samples recently evaluated. Results for the precision and accuracy are in terms of the percent recovery of surrogate compounds. The control limits for the Shewhart charts are also calculated. Since this set of data covers only a very short period of time and a small number of batches, the control limits are not representative of overall laboratory performance. The results obtained for the limits of the data as indicated in Table 3 may indicate that some of these data are unsuitable for the barest qualitative determination at the concentration level represented by the surrogate while other results are quantitative. The accuracy, precision and control indicators enable the data user to quantitatively evaluate the site data and determine the significance[3] between and among field results.

As can be seen from the tables, the same samples yield very different results for the different analyte categories. The quality obtainable for the analysis of samples is a function of many interacting variables which may be monitored but not necessarily controlled to the desired degree. While it is possible and desirable to indicate a minimally acceptable degree of data quality or in-

RANGES

$\bar{R}$ IS THE AVERAGE OF THE RANGE OF RECOVERY FOR THE DUPLICATE SAMPLES

$$UCL_{\bar{R}} = D_4 \bar{R} \qquad \text{UPPER CONTROL LIMIT}$$

$$UWL_{\bar{R}} = \frac{1 + 2D_4}{3} \bar{R} \qquad \text{UPPER WARNING LIMIT}$$

AVERAGES

$\bar{\bar{X}}$ IS THE GRAND AVERAGE OF THE MEANS OF BATCHES

$$UCL_x = \bar{\bar{X}} + A_2 \bar{R} \qquad \text{UPPER CONTROL LIMIT}$$

$$LCL_x = \bar{X} - A_2 \bar{R} \qquad \text{LOWER CONTROL LIMIT}$$

$$UWL_x = \bar{\bar{X}} + 2/3 \, A_2 \bar{R} \qquad \text{UPPER WARNING LIMIT}$$

$$LWL_x = \bar{\bar{X}} - 2/3 \, A_2 \bar{R} \qquad \text{LOWER WARNING LIMIT}$$

FOR n 2:

$$D_4 = 3.267$$

$$A_2 = 1.880$$
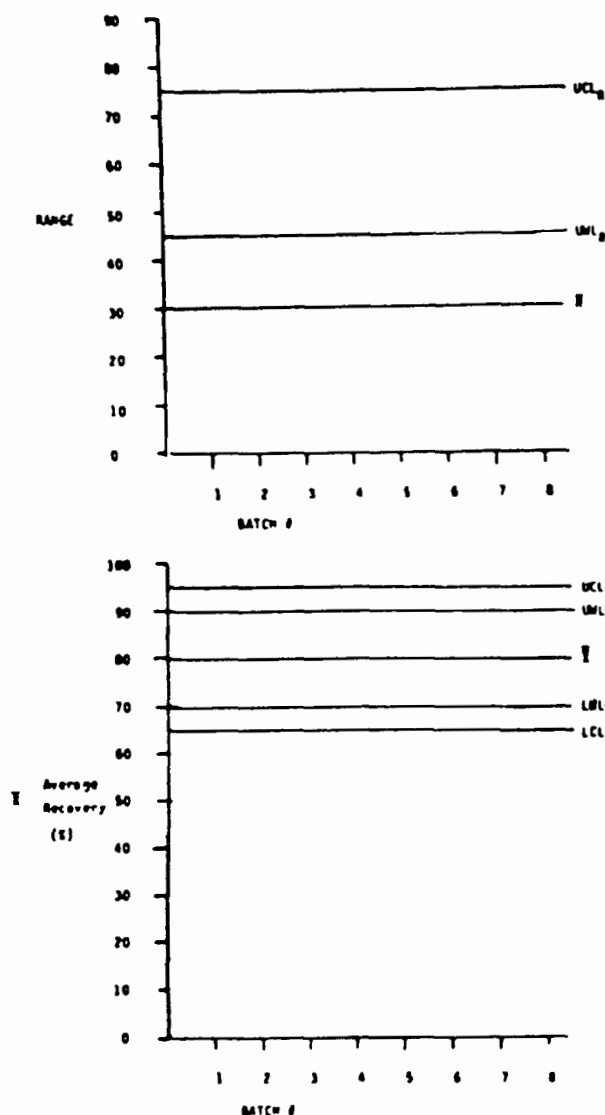
Figure 3
Construction of Control Charts

formation content, that degree may not be achievable due to a lack of an adequate method as surely as operational difficulties. The QC procedures embedded in the analytical process are present to ensure the data generator and the data user the ability to discriminate between these complications.

Three control charts generated from a volatile organic surrogate, a base/neutral surrogate and an acid surrogate are shown in Figure 6. The control charts were derived from several analytical batches of samples arising from a particular study from a hazardous waste site. The amount of data generated by several analytical batches from one site is insufficient to make a generalization concerning the control posture of the laboratory for those analyses. Inspection of the control and warning ranges for the determination of these compounds indicates a wide variation in the recoveries and ranges of results to be expected when the mandated methods are used to determine constituent analytes. The width of the ranges determined for the base/neutral compounds indicates that the variation in recovery may be unacceptably large while the average recovery of the acid compound may be unacceptably low.

The quantitative description of data quality allows the user to judge the appropriateness of data in terms of the information content of the data and the relevance of the data to the objective of the data-gathering activity. The user requirements for the data should not dictate how well defined the data are, but how useful the data are with respect to the defined quality. Data appropriate to certain legal proceedings may only have to establish the presence of the material in amounts significantly different from background or environmental levels. Remedial requirements may demand the establishment of significance between concentrations of analytes in adjoining samples.

The operational aspects and the degree to which the quality of the data are defined are approximately the same in both legal and remedial situations. The requirements in terms of the extent of information contained in the data are different. The differences in information content needed by the user may indicate that different ways of generating the required data may be appropriate. This, in turn, may require different techniques of data evaluation.

DISCUSSION

Quantitative procedures provide a tool which enables a more rational interpretation of field data as a function of physical phenomena through an understanding of the limitations on the data. These procedures, when consistently applied, also provide the means for defining the analytical process as it relates to laboratories, methods, matrices and the inter-relationships among these variables.

Using surrogates as a determinant of laboratory quality has the advantage of obtaining results that are unbiased by field sampling and environmental contamination. That is, the replicate precision of results is unaffected by the precision of sampling since surro-
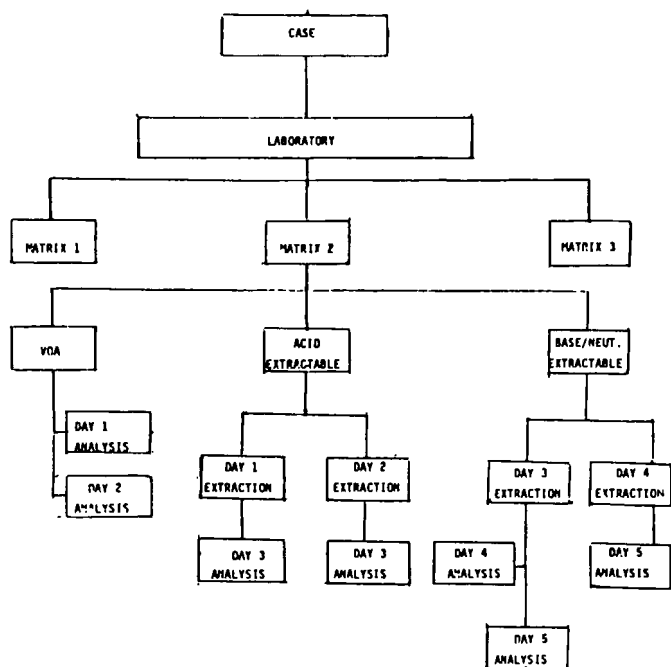
Figure 4
Segregation of Data into Analytical Batches

gate compounds are added to samples in the laboratory before analysis. The presence of the compound in the field sample negates contributions to inaccuracy and imprecision as occur in the situation with spiking actual pollutants. Using these compounds also negates the extra costs and resources required to analyze more samples in duplicate as background and spiked samples or accept a lower level of confidence due to gathering infrequent and less representative QC data. Finally, the use of a consistent set of compounds at similar concentrations across many laboratories and within a laboratory over a long period of time allows the gathering of data to establish performance characteristics of any variable or group of variables which can be isolated in the analytical process.

As a probe of analytical quality, surrogate compounds have certain drawbacks. The surrogate compound behavior must be correlated to the analytical behavior of the hazardous compounds and may not be direct indicators of analytical quality as related to in-

Figure 5
Symbolic Data
Top in numerical sample order; bottom sorted by date.
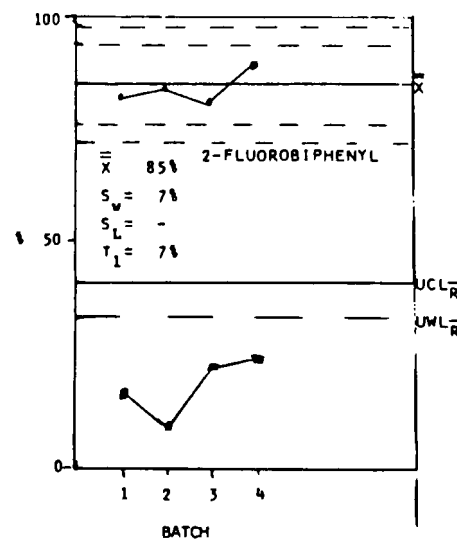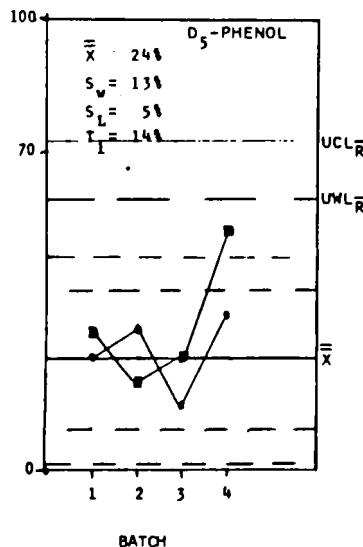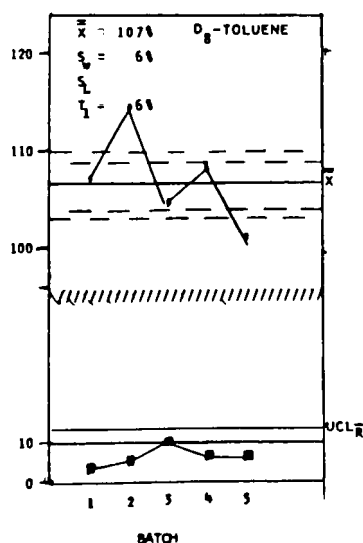
Figure 6
Control Charts of the Ranges and the Averages

Table 3A
Batch Statistical Data (%)

SURROGATE COMPOUND	BATCH 1 $\bar{x}_1$	STD. DEV	BATCH 2 $\bar{x}_2$	STD. DEV.	BATCH 3 $\bar{x}_3$	STD. DEV
D_8-TOLUENE	91	5	91	5	91	5
D_4-1,2-DICHLOROETHANE	94	5	99	3	99	5
BROMOFLUOROBENZENE	85	4	87	4	90	7
D_5-NITROBENZENE	50	17	58	20	84	16
2-FLUOROBIPHENYL	74	12	84	19	86	19
D_{10}-PYRENE	80	41	95	13	100	18
D_{14}-p-TERPHENYL	77	16	89	14	96	32
D_5-PHENOL	23	5	31	13	18	6
2-FLUOROPHENOL	44	10	41	14	33	13
2,4,6-TRIBROMOPHENOL	31	22	36	32	44	24
DIBUTYLCHLORENDATE	85	16	84	10	83	7

Table 3B
Summary Data (%)

SURROGATE(MATRIX)	ACCURACY $\bar{\bar{x}}$	PRECISION L		T_1	CONTROL $\bar{a}$	L/UCL	UCL
D_8 - TOLUENE	92	4	-	3	3	86/98	10
D_4-1,2-DICHLOROETHANE	95	5	3	4	5	92/101	10
BROMOFLUOROBENZENE	88	4	2	4	5	79/97	16
D_5-NITROBENZENE	57	25	19	21	30	1/113	90
2-FLUOROBIPHENYL	79	25	15	21	33	17/141	108
D_{10}-PYRENE	84	31	20	30	23	41/127	73
D_{14}-p-TERPHENYL	84	27	16	25	31	26/142	101
D_5-PHENOL	26	17	10	14	8	11/41	26
2-FLUOROPHENOL	43	35	23	36	15	15/71	49
2,4,6-TRIBROMO-PHENOL	39	33	14	50	47	0/127	154
DIBUTYLCHLOREN-DATE	86	25	19	17	12	64/108	39
1,2,3,4-TCDD	54	27	25	14		-	

dividual analyte behavior. Compounds that are added to samples may not faithfully mimic the matrix/compound interactions of those analytes that are environmentally present. Knowledge of the correlation of the analytical behavior of surrogate compounds with that of the analytes in various matrices would be helpful in understanding the results of analyses.

The more QC information on which data evaluations are based, the greater the probability that these evaluations are describing reality and not anomalies. This points up the need to automate the collection and analysis of QC data.

Applying statistical and manufacturing quality control to laboratory analyses provides an unbiased procedure for gauging the quality of analytical data and thereby establishing the information content of the analytical results. These statistical attributes of the data establish a system for defining the accuracy and precision of the analytical data and the control posture of the analytical labor-atory with respect to these procedures and samples. The variable nature of the sample/method interaction requires that the data evaluator take the perspective of defining the information content for the data user rather than enforcing a more or less arbitrarily chosen quality standard. The analytical result must have a level of quality associated with it consistent with its uses. If this level cannot be achieved consistently, other paths to the result must be chosen.

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CHARACTERIZATION OF ORGANIC WASTES FOR EVALUATION OF REMEDIAL ACTION ALTERNATIVES

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INTRODUCTION

Using conventional sampling and analytical techniques, investigators very often identify only a fraction of constituents present in complex organic hazardous wastes. Such techniques as gas chromatography/mass spectrometry (GC/MS) used to determine organic priority pollutants are widely recognized as vital to hazard assessment and do provide an essential initial characterization. However, the following constraints and considerations must be realized.

•Many high molecular weight organic compounds cannot be identified or quantified by GC/MS methods due to system limitations and sample behavioral properties. If a portion of the sample is not soluble in the extraction solvent or will not aspirate, for example, it will not reach the system at all.

•All GC/MS systems were not created equal. System capabilities differ widely. The minimal "economy" models can often only identify and quantify listed priority pollutants. Research-grade systems—especially, used in conjunction with gel permeation, capillary tubes and other ancillaries—provide much broader capability.

•In a complex waste matrix, detection limits of many constituents may be quite high, even though these constituents may represent significant hazard or may affect use of certain remedial action technologies.

•Analytical or administrative standard procedures often limit the information provided in conjunction with analytical reports. Due to standards of identification or quantitation confidence limits, statements like "present but not quantified" or "present below quantitation confidence limit" appear in detailed laboratory report appendices. Also, contract limitations for analytical services often pre-establish the number of organic constituent peaks beyond listed priority pollutants to be identified. Thus, conclusions in site investigation reports regarding presence or absence of certain constituents or classes of chemicals are valid only to the degree that the analytical and reporting procedures are comprehensive.

•The Contract Laboratory Program (CLP) is designed for bulk conventional analytical services, with some provisions for special analytical services (SAS). However, some capabilities simply are not available through CLP or require significant additional effort by all parties to arrange. As a result, the tendency to simply select analytical parameters from the available standard menu generally prevails.

Of critical importance in evaluation of remedial action alternatives is the assessment of whether specific technologies for destruction, hazard reduction or isolation are applicable and feasible for a specific site. Often, these technology assessments are based on one or two episodes of conventional sampling and analyses with inherent constraints described above. Further, sampling methods must be considered regarding representative results for each media.

Inevitably, the gap between analytical results and feasibility assessments proves very broad, yet it must be bridged. For feasibility assessments, a reasonable prediction of how a given waste material will react in many engineering situations is required. Predictive ability is fairly good for specific chemicals and moderate for a few waste materials and mixtures that have been previously studied or tested. However, no experience base exists for many complex organic matrices resulting from random disposal practices typical of uncontrolled hazardous waste sites.

Additional characterization and testing methods, beyond conventional analytical approaches but not including field trials or pilot tests, can be utilized to bridge the gap between investigation efforts and feasibility assessments with improved confidence. Analytical or behavioral testing of the actual waste material, preferably in or close to the physical state and condition anticipated for handling, is often needed. Some of these methods, developed for actual site investigations and feasibility assessments, are described in this presentation.

It is important that a site-specific approach must be developed in each case. Use of multiple laboratories, including both private and contract laboratories, may be necessary to obtain the desired capabilities for a given site investigation. Further, information and data obtained for feasibility purposes may not require the normal degree of quality assurance/quality control and evidentiary procedures.

FIELD TECHNIQUES

Pit Profiling

Many uncontrolled hazardous waste sites have resulted from the disposal of hazardous materials in open pits (Fig. 1). These waste pits can contain multiple layers including floating material, water, oils, other organic layers and bottom sludges. In addition to depth probing, the nature and variability of stratification must be determined. While sampling with depth in various locations in waste pits is generally necessary, the number of samples and cost of analyses—in addition to labor and expense—to effectively determine stratification can be substantial.

After a review of numerous probing methods, a technique for measuring in situ viscosity was developed for a site with numerous

pits containing complex organic wastes. A viscosity profile as a function of depth was performed at multiple locations in each pit using a modified Nametre Model 7.006 C4P vibrating sensor (probe) viscometer powered by a 12V battery (see Fig. 2). All factory-supplied gaskets were replaced with Viton gaskets. A 1.0 in. diameter steel pipe attached to the viscometer served as a handle and as a conduit for the transducer cable, which was also encased in Teflon. This unit had a digital readout and a maximum range of 0.1 to 100,000 centipoise (cp). The viscometer, connected at the bell housing to a steel winch cable, was raised and lowered using a manual winch with position-lock features.

Prior to each use, the viscometer was zeroed and the calibration checked. At each profile location and depth, the reading was allowed to stabilize prior to recording the data. After each use, the immersed sections were solvent-cleaned and rinsed.
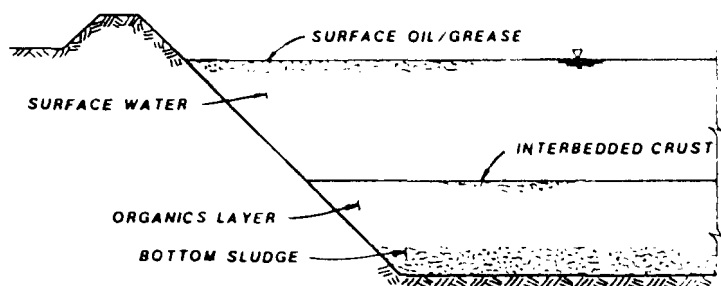
Figure 1
Typical Waste Pit Section
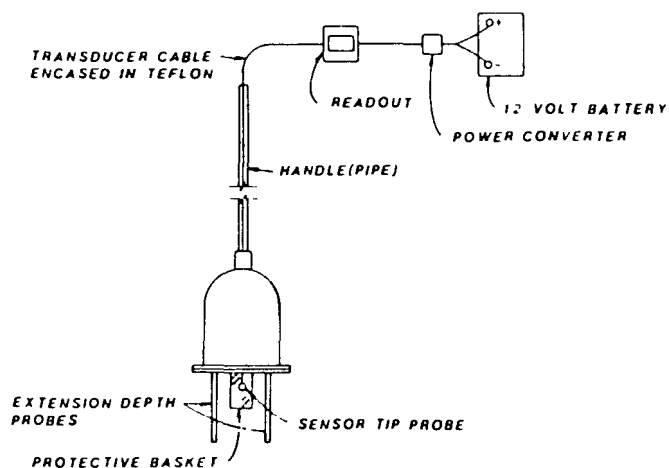
Figure 2
Viscometer Schematic

Total pit depths were measured at viscosity profile locations and a few additional locations, using either a separate depth probe rod or the viscometer equipped with two bottom probe extensions.

This method of assessing variability and stratification proved to be very effective, since viscosity variation between layers was substantial. Viscosity is a parameter needed to evaluate almost all handling and processing alternatives. An additional benefit of determining the viscosity of materials is that viscosity is proportional to molecular weight for many organic substances. Hence, data gathered through in situ viscosity profiling was used to select locations for sampling, thereby reducing the number of samples.

The organic strata profiled also contained numerous volatile organics which would be released if samples were brought to the surface in open containers. In previous sampling efforts at this site, observations of high rates of release of volatile chemicals and corresponding apparent viscosity increases had been reported. Thus, in situ viscosity measurements provided valuable information on handling properties such as pumpability of the various layers.

Contained-Volatiles Sampling

In most sampling, few precautions are taken to contain volatile chemicals. In pits, in situ absolute pressures may exceed 7 psig at 16 ft liquid depth. A reduction in pressure as the sample is raised to the water surface causes a release of volatiles. This loss occurs when one uses traditional sampling techniques such as column liquid sampling (coliwasa), thieves, dredges and pumping. Similar problems occur with monitor well sampling methods.

Additional releases of volatiles can occur in subsequent handling of samples. Resulting analyses can therefore indicate a volatiles content substantially less than actually present. Also, due to the above considerations, laboratory analyses may yield results below detection limits or of low confidence, particularly in a complex waste matrix.

The content and nature of volatile organic compounds can have a critical impact on remedial action feasibility assessment and ultimate implementation. Organic constituents have been demonstrated to limit use of many fixation/stabilization alternatives.

Volatile release could cause considerable damage to public health and the environment through ambient air quality degradation, particularly if a release is not expected during remedial action. Further, many organic chemicals are reactive in the liquid and/or vapor phases under certain conditions.

At the same site where in situ viscosity profiles were obtained, the release of volatile chemicals was a major concern. In prior sampling efforts, releases had been observed during sampling and contained-volatiles sampling of organic liquids in multiple pits was deemed necessary. To achieve sampling objectives, critical requirements of the sampling method and equipment were to:

- Collect and maintain the same at in situ pressures
- Contain the volatile compounds
- Prevent exposure to air, thereby reducing opportunities for oxidation and other reactions
- Provide a container of sufficient volume to be cooled (iced), transported and stored for laboratory use
- Provide for access to the contained volatiles for headspace analyses

Commercially-available sampling equipment, such as down-hole sampling bombs used in oil and gas well drilling, were reviewed but no applicable units were found. Special modifications to commercially available 2 gal stainless steel pressure vessels were made for collecting contained-volatiles samples. Because samples remained in the collection vessel until laboratory analyses were complete, one vessel was required for each contained-volatiles sample.

A schematic diagram of this sampling device, termed a remotely-actuated single point sampler (RASP), is shown in Figure 3. This device was equipped with a combination vacuum/pressure gage, a pressure relief valve pre-set at the vessure pressure rating which was much higher than any anticipated pressures, a septum for obtaining headspace vapor samples and a thermowell. Viton gasketing was used to seal the removable lid, opened to transfer samples to additional containers only after completion of initial headspace analyses and collection of aliquots for additional analyses of raw samples. Manual and pneumatic valves constructed of PVDF-Kynar were used for isolation and remote operation. The pneumatic valve was remotely operated using nitrogen through Teflon hoses jacketed in flexible woven stainless steel.

Prior to field mobilization, each completed sampler was thoroughly solvent cleaned, rinsed and purged with nitrogen. Then, each was tested for seal integrity to maintain both vacuum and

pressure conditions. Evacuation and purging with nitrogen were performed in three cycles, with the final purge of greater than ten volumes of nitrogen gas. Each unit was then pressurized to about 10 psig with nitrogen for storage and shipment and inscribed with serial identification markings.

In the field, samplers were operated as follows:

- A vacuum was pulled on the sampler reducing the pressure to about 7 psia just prior to sampling; the actuated valve was attached (closed) and the manual valve opened.
- The sampler was lowered to predetermined depth at the sample location.
- The actuated valve was opened for 1 to 2 min to allow sample collection through pressure equilibrium.
- The actuated valve was closed, the sampler raised and returned to shore.
- The manually operated valve was closed; then the actuated valve was removed.
- Finally, the system was decontaminated and the sample was labelled, iced and transported to the laboratory under chain-of-custody procedures.

During sample collection, each sample vessel was at the in situ pressure at the selected sampling location and depth. Using the vacuum/pressure gage and thermowell, the temperature, pressure and vessel weight were recorded, indicating the amount of sample obtained and the sampling conditions. Through this procedure, sample integrity was maintained including containment of volatiles; only inert nitrogen gas and vessel surfaces had contacted the sample.

Under controlled laboratory conditions, each sample vessel was subsequently heated in a water bath to a desired temperature while the pressure was monitored. When the desired temperature equilibrium was reached, an actual headspace sample was withdrawn through the septum on each vessel and directly analyzed using gas chromatography. As a result, numerous volatile compounds were identified which had not been previously reported, and much more representative volatiles characterization was performed than analysis of the bulk liquid matrix alone could provide.

After headspace analyses, sample vessels were cooled to allow aliquots to be collected for additional analyses without significant volatiles release.

Analytical Equipment

It has been estimated by the USEPA that 40% to 70% of the samples submitted to the Contract Laboratory Program yield negative extractable organics results (none present above detection limits). As a result, increased efforts to screen negative samples are underway to ease massive seasonal analytical backlog and more effectively utilize sophisticated analytical capabilities.

Photo-ionization and flame-ionization detector equipment (HNu/OVA) for indications of total organic vapors have been commonly used for health and safety as well as general sample screening. Zero instrument response indicates an absence of organic vapors. A positive instrument response, however, is not conclusive evidence of the presence of toxic organics. Also, most organic vapor meters accept samples only in the vapor phase. However, these equipment types have proven useful for screening samples not requiring volatile organic analyses.

Some available organic vapor analyzers also are capable of specific constituent identification and quantitation, although actual use has generally been limited. Increasingly, field OVA screening in the analytical mode and "close-support" field-portable or trailer-housed gas chromatography systems will be available. These systems should be considered not only in site investigations, but also during cleanup operations for fast turnaround analyses upon which remedial action staff can base field decisions. Additional systems which may prove applicable to specific sites include infrared (IR) and fluorometric analyses, where correlations to types and levels of contamination can be established.
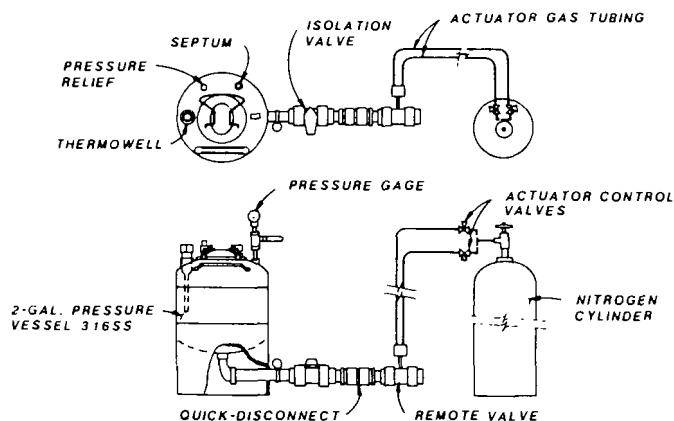
Figure 3
Remotely Actuated Single Point Sampler (RASP)

ADDITIONAL ANALYTICAL METHODS

Analytical methods in addition to GC/MS systems for organics include atomic adsorption or ICAP for inorganics as well as other traditional wet chemistry which can be used to gather specific information and data for a more effective assessment of feasible technologies.

Incineration Parameters

Thermal destruction through waste incineration is being increasingly considered as preferable to land disposal. Of particular importance in initial assessments of incineration feasibility are heat value, ash content, moisture content, total halogens and total chlorine of the waste. An additional test sometimes utilized is ash fusion.

Elemental Analyses

Analyses of total carbon, hydrogen, nitrogen, oxygen, sulfur and phosphorus are often useful to assist in identifying higher molecular weight organics. These constituent analyses are present in similar ratios for various classes of organic compounds.

Hazardous Waste Characteristics

Ignitability, corrosivity and extraction procedure (EP) toxicity testing according to RCRA criteria can be used for categorizing wastes and generated residuals and for determining the hazard classification. Total cyanide can also be useful regarding reactivity and hazard potential.

Molecular Weight

A number of methods, some of which are quite sophisticated, are available for number-average or weighted-average molecular weight analyses. These results can be very useful in identifying high molecular weight organic compounds, although the value of this test is limited for complex mixtures.

Fractionation

Samples can be separated into various fractions through distillation, solvent extraction, etc. Of particular value in solvent systems is a modified ASTM distillation test using overhead condensers to separate organic mixtures into fractions according to boiling point ranges. The fractions can then be analyzed separately for desired parameters.

At one site, this method showed that a complex organic waste mixture could be separated so that 95% of the most hazardous chlorinated solvents could be concentrated in 5-10% of the original weight. Additional process design information can be gathered from this test if distillation to separate fractions appears feasible for a given waste media.

BEHAVIORAL PARAMETERS

In addition to analytical approaches, it is often desirable to determine how a waste material will behave under certain conditions. Using standard testing methods, or method developed for a specific case, behavioral parameters can usually be defined.

Thermal Analyses

Differential thermal analysis (DTA) is used to measure the temperature differential with heating between two sample pans, one containing a ballast of aluminum and/or alumina and the other holding the material to be analyzed. Any thermodynamic change such as melting, evaporation or reaction (oxidation, decomposition, etc.) will cause a temperature differential between the pans and a subsequent exothermic or endothermic peak recorded at the temperature of occurrence. Typically, this DTA process can be conducted from 32 to 930°F at selected and controlled temperature rise rates, such as 36°F/min.

Thermal gravimetric analysis (TGA) generally involves placement of a small (5-10 mg) sample in a platinum pan which is continuously weighed on an electrobalance while the sample is heated to 930°F in a nitrogen atmosphere. Volatiles release, decomposition and other reactions are indicated in terms of weight loss as a function of temperature.

Results of these tests directly indicate sample behavior at various temperatures and can be compared to behavior of known chemicals for comparison and identification purposes. In addition, admixtures or testing in other atmospheres (air, oxygen, etc.) can be utilized to assess impacts of various conditions on the behavior of the material.

Vapor Pressure Versus Temperature

If reasonably representative contained-volatiles samples can be obtained, a plot of the vapor pressure versus temperature can be readily obtained. These data provide information needed for closed system handling, such as required system pressure ratings under various conditions. In addition, indications of the nature and content of volatile compounds in the waste material can be obtained.

Viscosity

Viscosity is an important parameter in many waste handling and processing operations. Examples of the need for viscosity data include pumpability and feasibility of injection through feed nozzles in liquid injection incinerator systems. Measurements of viscosity versus temperature for heavy organics provides an indication of whether heating can be used to improve flow properties as practiced in numerous industries (asphalt, crude oil, etc.). Addition of selected solvents or petroleum derivatives (i.e., kerosene) can be assessed for modifying flow properties through viscosity measurements. Sometimes even small percentage admixtures can have a pronounced effect on handling properties.

CHEMICAL COMPOSITION OF DRUM SAMPLES FROM HAZARDOUS WASTE SITES

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INTRODUCTION

Samples taken from drums, tanks, other containers and samples suspected of having high concentrations of hazardous waste from 221 disposal sites in 41 states and one territory have been prepared for analysis by the Regulated Substances Laboratory (RSL), USEPA National Enforcement Investigations Center (NEIC), operated under contract to the USEPA Contract Laboratory Program (CLP) by Fred C. Hart Associates, Inc. These samples were taken from a wide spectrum of hazardous waste sites by the USEPA and state personnel and contractors retained by the USEPA for the conduct of hazardous waste site evaluations. After preparation in the RSL, these samples were analyzed in environmental laboratories of the USEPA regions, the NEIC and in eight CLP laboratories.

The data generated by these analyses are believed to generally represent the chemical content of drums and other waste containers on hazardous waste sites throughout the nation and provide policymakers, industry and regulatory agency managers, investigators and analysts with a basis for greater confidence in decisions regarding exposure risks to the public and to personnel engaged in hazardous waste site evaluations.

The data presented in this paper should be considered reliable to the degree of accuracy and precision required by the contracts under which they were obtained and achievable through reasonable quality control checks in the collection and compilation thereof. Appendix A is abstracted from the Registry of Toxic Effects of Chemical Substances (RTECS), published by the National Institutes of Occupational Health and Safety (NIOSH). The reader is cautioned that the Appendix A summary is intended to be a general overview. The original sources referred to by RTECS should be consulted for specific characteristics of any of the listed chemicals. The conclusions reached in this paper are those of the authors and are not policy statements of the Environmental Protection Agency.

Historical Perspective

In 1979, as the USEPA began the hazardous waste site cleanup programs, the Agency had relatively minor experience with and essentially no procedural criteria for the field investigation of sites, packaging and shipping of potentially hazardous samples or the laboratory preparation and analysis of samples suspected of containing high concentrations of hazardous materials. Criteria were quickly developed, based upon the limited experience and professional judgment available within the Agency. This early guidance was provided to USEPA and state technical staffs and contractors through a number of procedures manuals, several of which were adapted from internal procedural documents of the NEIC[1, 2, 3, 4] contractor procedures[5] and Department of Transportation regulations.[6]

The early guidance documents reflected the extreme concerns held by their authors and proponents for the safety of field investigators, the transportation industries, laboratory personnel and the general public. This concern was based upon good understanding of the potential for spills, releases, exposures, fires and explosions, but less certain knowledge of preventive measures and procedures which could be depended upon to prevent such events under any and all conceivable field, transportation and laboratory circumstances.

At the NEIC, the operational manifestation of these understandings was a consistent effort to "err on the side of safety". This policy permeated site investigation plans; training of NEIC employees and training provided by NEIC to other USEPA, state and contractor personnel; and continuously updated sample packaging and shipment procedures and RSL procedures. Other USEPA elements adapted or adopted portions of these procedures, modified or added to them to meet local and Regional requirements or developed criteria and procedures independently. Regardless of the degree or extent of independence, the conservative philosophy toward safety aspects appears to have been generally adopted throughout the Agency.

ANALYTICAL PROCEDURES

The samples which are the subject of this paper were taken from drummed material, waste pits or ponds, piles of waste, tank trucks or on-site tanks and contaminated soils. Many of the samples were used oil, spent solvents, paint wastes, metal treatment and plating wastes and polymer formulations. They were usually industrial process wastes, waste raw materials and byproducts, synthesis intermediates and off-specification products. The RSL, operating in a containment laboratory configuration and under strict containment laboratory procedures, received 8 oz hazardous waste samples as shipped and provided initially screened and diluted aliquots of each defined phase. Many of the samples contained two or more phases when received by the RSL. Phases were separated and preparations were made from each defined phase.

The organic analytical regime to which the preparations have been subjected by CLP laboratories has varied somewhat according to the contract language in force at any given time. From 1980 to 1982, the specified organic analyses included 113 priority pollutants and a maximum of 30 mass spectrometry library identifications (tentative identifications). From 1982 to the present, the organic analyses included an additional 20 non-priority pollutant organic substances. The categories included 11 priority pollutant organic

acids, 45 priority pollutant organic bases and neutrals, 31 priority pollutant organic volatile solvents, 26 priority pollutant organic pesticides and polychlorinated biphenyls (PCBs) and the 20 additional organics mentioned above (Table 1).

The contract requirement for analysis of these organics, which are detectable by gas chromatography, imposes certain limitations which should be recognized by the reader. Many common industrial chemicals either have poor extraction efficiencies or do not chromatograph. Polymers, carboxylates, glycols, sulfonates, phosphates and low molecular weight alcohols, amines and aldehydes will not be qualitatively or quantitatively analyzed by the methods specified. In addition, the pesticides/PCB analysis includes only priority pollutant chlorinated hydrocarbon pesticides and excludes carbamate and organophosphate insecticides and nitrogenous or phenoxy herbicides. Constituents of these categories may have been identified by analytical procedures available under the later Special Analytical Services (SAS) contracts, when specified, but the great majority of samples reported upon in this paper were not subjected to these additional analyses.

The inorganic analyses were performed by inductively coupled argon plasma spectroscopy (ICP), atomic adsorption spectroscopy (AA) and colorimetry. Approximately 300 samples were subjected to procedures which identified and quantified 13 priority pollutant elements, cyanide and 20 additional inorganic elements. Approximately 1,300 samples were analyzed for 35 inorganics.

ANALYTICAL RESULTS

The analytical procedures described yielded the organic data summarized in Table 2 and the inorganic data similarly provided in Table 3. The average number of analyses for organic constituents was 1,100. These constituents were detected by only 3% of the analyses (detected/analyzed). The average number of analyses for inorganic constituents was similarly 1,200 but, in contrast, the inorganics were detected by 39% of the analyses.

The average of the mean concentrations of the 114 reported values was 576 mg/l, while the average mean concentration of the 36 reported values greater than 100 mg/l was 1,728 mg/l. The organic chemicals with the highest reported maximum concentrations (in percentages) are 2-methylphenol (90%); trichloroethene (82%); o-xylene (79%); chlordane (78%); acetone (76%); 1,1,1-trichloroethane (72%); and benzene (60%). Significantly, 39% of

the 133 organic chemicals were detected in only four or fewer samples. Moreover, 64 organic constituents were detected in less than one of every 100 samples.

The average of the mean concentrations of the 35 inorganic constituents, all of which were detected in some samples, was 1,836 mg/l, while the average mean concentration for the 16 reported values greater than 100 mg/l was 3,876 mg/l. The highest reported maximum inorganic concentrations were iron (94%); sodium (86%); zinc (75%); lead (66%); silicon (38%); and calcium (35%). The inorganics detected in the fewest samples were cyanide (2.7% of times analyzed) and thallium (8.0% of times analyzed).

Finally, more than 450 additional non-target organic constituents were tentatively identified or quantified. A listing of these constituents may be obtained by contacting one of the authors at the NEIC.

SIGNIFICANCE OF CHEMICAL CONSTITUENTS IDENTIFIED

An exhaustive evaluation of the significance of each detected chemical constituent is not possible in this paper. However, a summarized tabulation which will enable the reader to quickly gain a sense of the general nature of any of the 133 organic and 35 inorganic target constituents is given in Appendix A. The Appendix A indicators are: (1) priority pollutant per the NRDC v. Train consent decree;[1] (2) inclusion in the Department of Transportation (DOT) regulations pertaining to transport of hazardous materials;[4] (3) chemical or compound for which an Occupational Safety and Health Administration (OSHA) standard pertains;[1] (4) one or more of the RCRA/CERCLA indicators[9]—EP toxicity, ignitability, persistence, reactivity, corrosiveness; (5) severe toxicity to a test animal;[1] (6) severe reproductive effect;[1] (7) severe irritation (skin or eye);[1] (8) known carcinogen;[1] (9) mutagen;[1] or (10) teratogen.[1] Some general conclusions regarding environmental hazards, exposure risk to field investigators, exposure risk to laboratory personnel and shipment of hazardous waste samples, are offered in subsequent sections of this paper.

Environmental Significance

A sense of the chemicals present in more plentiful quantities on hazardous waste sites may be had by the weighting scheme provided in Tables 4 (organics) and 5 (inorganics). Mean concentra-

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Table 1
Target Chemical Constituents by Category

ORGANIC ACIDS

1 2,4,6-Trichlorophenol	5 2,4-Dimethylphenol	9 4,6-Dinitro-o-Cresol
2 p-Chloro-m-Cresol	6 2-Nitrophenol	10 Pentachlorophenol
3 2-Chlorophenol	7 4-Nitrophenol	11 Phenol
4 2,4-Dichlorophenol	8 2,4-Dinitrophenol	

ORGANIC BASES AND NEUTRALS

12 Acenaphthene	27 4-Chlorophenyl Phenyl Ether	42 Diethyl Phthalate
13 Benzidine	28 4-Bromophenyl Phenyl Ether	43 Dimethyl Phthalate
14 1,2,4-Trichlorobenzene	29 Bis(2-Chloroisopropyl) Ether	44 Benzo(a)Anthracene
15 Hexachlorobenzene	30 Bis(2-Chloroethoxy)Methane	45 Benzo(a)Pyrene
16 Hexachloroethane	31 Hexachlorobutadiene	46 Benzo(b)Fluoranthene
17 Bis(2-Chloroethyl)Ether	32 Hexachlorocyclopentadiene	47 Benzo(k)Fluoranthene
18 2-Chloronaphthalene	33 Isophorone	48 Chrysene
19 1,2-Dichlorobenzene	34 Naphthalene	49 Acenaphthylene
20 1,3-Dichlorobenzene	35 Nitrobenzene	50 Anthracene
21 1,4-Dichlorobenzene	36 N-Nitrosodiphenylamine	51 Benzo(ghi)Perylene
22 3,3'-Dichlorobenzidine	37 N-Nitrosodipropylamine	52 Fluorene
23 2,4-Dinitrotoluene	38 Bis(2-Ethylhexyl)Phthalate	53 Phenanthrene
24 2,6-Dinitrotoluene	39 Benzyl Butyl Phthalate	54 Dibenzo(a,h)Anthracene
25 1,2-Diphenylhydrazine	40 Di-n-Butyl Phthalate	55 Indeno(1,2,3-cd)Pyrene
26 Fluoranthene	41 Di-n-Octyl Phthalate	56 Pyrene

ORGANIC VOLATILES

57 Acrolein	68 2-Chloroethylvinyl Ether	78 Bromomethane
58 Acrylonitrile	69 Chloroform	79 Bromoform
59 Benzene	70 1,1-Dichloroethene	80 Bromodichloromethane
60 Carbon Tetrachloride	71 Trans-1,2-Dichloroethene	81 Fluorotrichloromethane
61 Chlorobenzene	72 1,2-Dichloropropane	82 Dichlorodifluoromethane
62 1,2-Dichloroethane	73 Trans-1,3-Dichloropropene	83 Chlorodibromomethane
63 1,1,1-Trichloroethane	74 Cis-1,3-Dichloropropene	84 Tetrachloroethene
64 1,1-Dichloroethane	75 Ethylbenzene	85 Toluene
65 1,1,2-Trichloroethane	76 Methylene Chloride	86 Trichloroethene
66 1,1,2,2-Tetrachloroethane	77 Chloromethane	87 Vinyl Chloride
67 Chloroethane		

PESTICIDES, PCBs AND TCDD

88 Aldrin	97 Endrin	106 PCB 1254
89 Dieldrin	98 Endrin Aldehyde	107 PCB 1221
90 Chlordane	99 Heptachlor	108 PCB 1232
91 4,4'-DDT	100 Heptachlor Epoxide	109 PCB 1248
92 4,4'-DDE	101 a-BHC	110 PCB 1260
93 4,4'-DDD	102 b-BHC	111 PCB 1016
94 a-Endosulfan	103 d-BHC	112 Toxaphene
95 b-Endosulfan	104 g-BHC (Lindane)	113 2,3,7,8-Tetrachloro-
96 Endosulfan Sulfate	105 PCB 1242	dibenzo-p-Dioxin

ADDITIONAL ORGANIC SUBSTANCES

114 Benzoic Acid	121 Dibenzofuran	128 Carbondisulfide
115 2-Methylphenol	122 2-Methylnaphthalene	129 2-Hexanone
116 4-Methylphenol	123 2-Nitroaniline	130 4-Methyl-2-Pentanone
117 2,4,5-Trichlorophenol	124 3-Nitroaniline	131 Styrene
118 Aniline	125 4-Nitroaniline	132 Vinyl Acetate
119 Benzyl Alcohol	126 Acetone	133 o-Xylene
120 4-Chloroaniline	127 2-Butanone	

INORGANIC ELEMENTAL CONSTITUENTS

1 Aluminum	13 Lanthanum	25 Sodium
2 Antimony	14 Lead	26 Strontium
3 Arsenic	15 Magnesium	27 Thallium
4 Barium	16 Manganese	28 Tin
5 Beryllium	17 Mercury	29 Titanium
6 Boron	18 Molybdenum	30 Tungsten
7 Cadmium	19 Nickel	31 Vanadium
8 Calcium	20 Potassium	32 Yttrium
9 Chromium	21 Scandium	33 Zinc
10 Cobalt	22 Selenium	34 Zirconium
11 Copper	23 Silicon	OTHER
12 Iron	24 Silver	35 Cyanide

CAS	COMPOUND NAME	NUMBER OF TIMES ANALYZED	DETECTED	CONCENTRATION (PPM) MEAN	MAXIMUM
88-06-2	2,4,6-TRICHLOROPHENOL	1131	0	-	-
59-50-7	p-CHLORO-m-CRESOL	1131	3	0.41	310.00
95-57-8	2-CHLOROPHENOL	1131	3	0.73	820.00
120-83-2	2,4-DICHLOROPHENOL	1131	3	0.08	65.00
105-67-9	2,4-DIMETHYLPHENOL	1131	50	637.68	140000.00
88-75-5	2-NITROPHENOL	1131	1	0.07	76.00
100-02-7	4-NITROPHENOL	1131	0		
51-28-5	2,4-DINITROPHENOL	1131	0		
534-52-1	4,6-DINITRO-o-CRESOL	1131	0	-	-
87-86-5	PENTACHLOROPHENOL	1137	16	666.97	370000.00
108-95-2	PHENOL	1131	127	2406.95	400000.00
83-32-9	ACENAPHTHENE	1256	30	26.96	8400.00
92-87-5	BENZIDINE	1132	1	0.00	2.20
120-82-1	1,2,4-TRICHLOROBENZENE	1250	16	66.72	36000.00
118-74-1	HEXACHLOROBENZENE	1273	30	123.10	21000.00
67-72-1	HEXACHLOROETHANE	1250	3	8.57	8300.00
111-44-4	BIS(2-CHLOROETHYL)ETHER	1150	4	1.97	1800.00
91-58-7	2-CHLORONAPHTHALENE	1250	2	0.30	350.00
95-50-1	1,2-DICHLOROBENZENE	1250	50	1936.82	490000.00
541-73-1	1,3-DICHLOROBENZENE	1250	14	387.84	220000.00
106-46-7	1,4-DICHLOROBENZENE	1250	25	993.04	540000.00
91-94-1	3,3'-DICHLOROBENZIDINE	1239	0	-	-
121-14-2	2,4-DINITROTOLUENE	1250	2	0.06	78.00
606-20-2	2,6-DINITROTOLUENE	1250	1	0.06	78.00
122-66-7	1,2-DIPHENYLHYDRAZINE	1136	0	-	-
206-44-0	FLUORANTHENE	1256	65	66.87	42000.00
7005-72-3	4-CHLOROPHENYL PHENYLETHER	1239	0		
101-55-3	4-BROMOPHENYL PHENYL ETHER	1250	0	-	-
39638-32-9	BIS(2-CHLOROISOPROPYL)ETHER	1239	2	0.09	87.00
111-91-1	BIS(2-CHLOROETHOXY)METHANE	1250	1	0.06	78.00
87-68-3	HEXACHLOROBUTADIENE	1250	4	1.82	2000.00
77-47-4	HEXACHLOROCYCLOPENTADIENE	1272	28	58.72	14000.00
78-59-1	ISOPHORONE	1250	27	158.23	160000.00
91-20-3	NAPHTHALENE	1256	168	269.02	81000.00
98-95-3	NITROBENZENE	1250	2	0.24	220.00
86-30-6	N-NITROSODIPHENYLAMINE	1255	16	95.08	110000.00
621-64-7	N-NITROSODIPROPYLAMINE	1250	1	0.04	50.00
117-81-7	BIS(2-ETHYLHEXYL)PHTHALATE	1250	190	213.56	45500.00
85-68-7	BENZYL BUTYL PHTHALATE	1250	49	88.55	50000.00
84-74-2	DI-n-BUTYL PHTHALATE	1250	97	509.09	560000.00
117-84-0	DI-n-OCTYL PHTHALATE	1250	26	1.69	520.00
84-66-2	DIETHYL PHTHALATE	1250	47	25.29	4500.00
131-11-3	DIMETHYL PHTHALATE	1250	31	51.37	30000.00
56-55-3	BENZO(a)ANTHRACENE	1255	50	28.46	21600.00
50-32-8	BENZO(a)PYRENE	1248	36	10.87	7200.00
205-99-2	BENZO(b)FLUORANTHENE	1228	29	22.97	10200.00
207-08-9	BENZO(k)FLUORANTHENE	1243	23	22.02	10200.00
218-01-9	CHRYSENE	1256	46	27.72	21600.00
208-96-8	ACENAPHTHYLENE	1252	22	4.28	3800.00
120-12-7	ANTHRACENE	1256	77	218.47	126000.00
191-24-2	BENZO(ghi)PERYLENE	1250	14	1.45	400.00
86-73-7	FLUORENE	1256	58	45.56	16800.00
85-01-8	PHENANTHRENE	1256	110	227.92	126000.00
53-70-3	DIBENZO(a,h)ANTHRACENE	1250	3	0.09	98.00
193-39-5	INDENO(1,2,3-cd)PYRENE	1239	14	2.24	630.00
129-00-0	PYRENE	1255	79	50.44	33000.00
107-02-8	ACROLEIN	1052	0	-	-
107-13-1	ACRYLONITRILE	1052	2	19.96	21000.00
71-43-2	BENZENE	1225	104	577.29	600000.00
56-23-5	CARBON TETRACHLORIDE	1225	11	341.99	400000.00
108-90-7	CHLOROBENZENE	1225	50	85.38	57000.00
107-06-2	1,2-DICHLOROETHANE	1225	33	416.69	270000.00
71-55-6	1,1,1-TRICHLOROETHANE	1225	98	1318.02	720000.00
75-34-3	1,1-DICHLOROETHANE	1225	15	12.50	5000.00
79-00-5	1,1,2-TRICHLOROETHANE	1217	10	307.25	240000.00
79-34-5	1,1,2,2-TETRACHLOROETHANE	1225	10	256.09	310000.00
75-00-3	CHLOROETHANE	1225	1	0.05	57.00
110-75-8	2-CHLOROETHYLVINYL ETHER	1141	0	-	-
67-66-3	CHLOROFORM	1225	29	20.49	14000.00
75-35-4	1,1-DICHLOROETHENE	1225	22	14.11	9300.00
156-60-5	TRANS-1,2-DICHLOROETHENE	1225	18	3.86	4300.00
78-87-5	1,2-DICHLOROPROPANE	1225	22	91.50	40000.00
10061-02-6	TRANS-1,3-DICHLOROPROPENE	1140	3	0.02	10.00
10061-01-5	CIS-1,3-DICHLOROPROPENE	1140	0	-	-
100-41-4	ETHYLBENZENE	1225	375	2279.25	150000.00
75-09-2	METHYLENE CHLORIDE	1225	208	780.83	220000.00
74-87-3	CHLOROMETHANE	1224	4	0.38	337.00
74-83-9	BROMOMETHANE	1225	1	0.01	10.00
75-25-2	BROMOFORM	1225	0		
75-27-4	BROMODICHLOROMETHANE	1225	0		
75-69-4	FLUOROTRICHLOROMETHANE	1184	5	80.15	45000.00
75-71-8	DICHLORODIFLUOROMETHANE	1064	1	0.94	1000.00
124-48-1	CHLORODIBROMOMETHANE	1224	0	-	-
127-18-4	TETRACHLOROETHENE	1225	150	1345.26	170000.00
108-88-3	TOLUENE	1225	469	10208.85	440000.00
79-01-6	TRICHLOROETHENE	1225	106	2173.11	820000.00
75-01-4	VINYL CHLORIDE	1224	4	0.15	180.00
309-00-2	ALDRIN	1143	11	2.00	2000.00
60-57-1	DIELDRIN	1142	18	44.73	33000.00
57-74-9	CHLORDANE	1142	41	2548.44	780000.00
50-29-3	4,4'-DDT	1142	16	0.21	100.00
72-55-9	4,4'DDE	1142	20	0.04	23.00
72-54-8	4,4'DDD	1142	14	0.11	63.00
115-29-7	a-ENDOSULFAN	1142	13	0.04	22.00
115-29-7	b-ENDOSULFAN	1141	2	0.06	66.00
1031-07-8	ENDOSULFAN SULFATE	1141	2	0.08	86.00
72-20-8	ENDRIN	1142	6	0.01	2.80
7421-93-4	ENDRIN ALDEHYDE	1101	2	0.08	84.00
76-44-8	HEPTACHLOR	1142	48	115.90	110000.00
1024-57-3	HEPTACHLOR EPOXIDE	1142	10	0.01	6.80
319-84-6	a-BHC	1142	10	0.69	400.00
319-85-7	b-BHC	1142	9	0.07	35.00
319-86-8	d-BHC	1142	4	0.04	21.00
58-89-9	g-BHC (LINDANE)	1142	9	0.35	260.00
53469-21-9	PCB 1242	1142	27	2.80	1600.00
11097-69-1	PCB 1254	1145	34	5.21	3620.00
11104-28-2	PCB 1221	1142	1	0.00	0.01
11141-16-5	PCB 1232	1142	1	0.00	0.01
12672-29-6	PCB 1248	1145	18	8.87	8000.00
11096-82-5	PCB 1260	1144	37	390.36	140000.00
12674-11-2	PCB 1016	1143	6	0.12	119.00
8001-35-2	TOXAPHENE	1142	2	1.05	1200.00
1746-01-6	2,3,7,8-TETRACHLORO-DIBENZO-p-DIOXIN	972	6	0.00	0.60
65-85-0	BENZOIC ACID	508	16	131.64	20000.00
95-48-7	2-METHYLPHENOL	498	44	3827.72	900000.00
108-39-4	4-METHYLPHENOL	498	28	1128.10	110000.00
95-95-4	2,4,5-TRICHLOROPHENOL	498	0		
62-53-3	ANILINE	499	0		
100-51-6	BENZYL ALCOHOL	499	0	-	-
106-47-8	4-CHLOROANILINE	499	2	0.00	1.00
132-64-9	DIBENZOFURAN	502	9	38.80	12000.00
91-57-6	2-METHYLNAPHTHALENE	503	35	89.35	10000.00
88-74-4	2-NITROANILINE	499	0		
99-09-2	3-NITROANILINE	499	0		
100-01-6	4-NITROANILINE	499	0	-	-
67-64-1	ACETONE	510	40	6651.64	760000.00
78-93-3	2-BUTANONE	508	54	6902.96	565000.00
75-15-0	CARBONDISULFIDE	510	2	0.23	100.00
591-78-6	2-HEXANONE	510	14	1945.97	490000.00
108-10-1	4-METHYL-2-PENTANONE	512	46	1170.95	300000.00
100-42-5	STYRENE	510	26	1742.23	300000.00
108-05-4	VINYL ACETATE	510	6	231.18	58000.00
95-47-6	o-XYLENE	600	223	8388.21	790000.00

tion values have been converted to percent. Frequency detected is the number of times detected divided by the number of times analyzed. The product of the mean concentration and the frequency detected (X x F) yields a weighted frequency which represents the equal importance of these two variables. To facilitate ranking, the greatest weighted frequency (toluene and silicon) have been normalized to 100, and the other values have been adjusted accordingly.

The most prevalent 20 organic constituents have been ranked in Table 4. Based upon weighted frequency, the five most prevalent organics were toluene > o-xylene > 2-butanone > ethylbenzene > acetone. As indicated in Appendix A, two are priority pollu-tants, four are DOT regulated, four have applicable OSHA standards, all are toxics, four are ignitable, three are persistent, one is a mutagen and none are known carcinogens. These five organic constituents represent about 81%, by total weighted frequencies, of the total 133 target organics. The weighted frequencies of the remaining 15 organic constituents ranged from less than 1% to 9% of the weighted frequency for toluene.

The 20 prevalent organics of Table 4 included 12 priority pollutants, 17 DOT regulated substances, 18 OSHA regulated constituents, 18 toxics, 13 ignitables, 15 persistents, 14 constituents exhibiting severe reproductive effects, 13 severe irritants, 11 carcinogens, ten mutagens and seven teratogens. In fact, 12 of the 20 ex-

hibited nearly all of the Appendix A characteristics. These 20 organic constituents represent in excess of 97%, by total weighted frequencies, of all 133 target organic constituents.

In similar fashion, the 15 most prevalent inorganic constituents have been ranked in Table 5. Based upon weighted frequency, the seven most prevalent inorganic elements were silicon > iron > calcium > sodium > aluminum > potassium > titanium. These seven more prevalent inorganics include no priority pollutants nor known carcinogens. The seven represent nearly 90%, by total weighted frequencies, of all 35 target inorganics.

The weighted frequencies of the remaining eight elements ranged from less than 1% to 9% of the weighted frequency for silicon. This group of eight, having less than 10% weighted frequencies, includes the five inorganic priority pollutants found on Table 5: zinc, lead, chromium, copper and cyanide.

Table 3
Results of Hazardous Waste Analyses Inorganic Chemical Constituents

COMPOUND NAME	NUMBER OF TIMES ANALYZED	DETECTED	CONCENTRATIONS (PPM) MEAN	MAXIMUM
ALUMINUM(AL)	1311	737	4621.88	252000.00
ANTIMONY(SB)	1411	470	80.53	14400.00
ARSENIC(AS)	1492	507	114.45	143850.00
BARIUM(BA)	1363	620	476.98	143000.00
BERYLLIUM(BE)	1532	216	1.18	466.00
BORON(B)	1023	272	62.27	23400.00
CADMIUM(CD)	1565	444	14.02	5100.00
CALCIUM(CA)	1154	731	5705.22	353000.00
CHROMIUM(CR)	1574	834	806.30	312000.00
COBALT(CO)	1275	334	11.95	1110.00
COPPER(CU)	1529	877	521.81	95400.00
CYANIDE(CN)	1200	33	298.00	105000.00
IRON(FE)	1315	994	11674.65	938000.00
LANTHANUM(LA)	832	95	4.47	1150.00
LEAD(PB)	1578	780	2130.92	656000.00
MAGNESIUM(MG)	1152	697	1153.15	134000.00
MANGANESE(MN)	1320	842	155.31	43500.00
MERCURY(HG)	1167	291	3.17	1900.00
MOLYBDENUM(MO)	1086	148	91.01	17300.00
NICKEL(NI)	1533	565	146.85	156000.00
POTASSIUM(K)	446	297	3110.48	87500.00
SCANDIUM(SC)	963	167	0.53	18.50
SELENIUM(SE)	1417	261	11.83	1900.00
SILICON(SI)	967	566	20411.47	378000.00
SILVER(AG)	1553	207	1.52	271.00
SODIUM(NA)	1152	549	6966.18	856000.00
STRONTIUM(SR)	1081	602	43.54	6390.00
THALLIUM(TL)	1367	110	1.76	400.00
TIN(SN)	422	54	18.78	4100.00
TITANIUM(TI)	1084	610	2502.58	244000.00
TUNGSTEN(W)	942	127	19.94	13100.00
VANADIUM(V)	1315	358	6.92	365.00
YITRIUM(Y)	1046	195	4.09	372.00
ZINC(ZN)	1532	1105	1520.36	745000.00
ZIRCONIUM(ZR)	950	261	18.00	2190.00

The 15 Table 5 inorganics include the five priority pollutants, eight elements subject to DOT regulations, three elements for which OSHA standards exist, three RCRA/CERCLA toxics and, depending upon the specific form or compound present, several ignitables, reactives and corrosives. Also present are three inorganics having reproductive effects, two known carcinogens, two mutagens and two teratogens. These 15 inorganic constituents represent in excess of 99%, by total weighted frequencies, of all 35 target inorganic constituents.

Clearly, the chemical constituents present in drums, other containers and in contaminated soil on hazardous waste sites constitute potential or actual hazards to the environment and to the public health. The principle concern in the preparation of the early guidance[1,2,3] was the potential for contamination of aquifers which supply domestic water systems. This review lends no rationale for

Table 4
Prevalent Organic Constituents

Constituent	Mean Concentration % (X̄)	Frequency Detected % (F)	(X̄)(F)	(X̄)(F) Normalized to Toluene
Toluene	1.021	38.3	39.10	100
o-Xylene	0.839	37.2	31.20	80
2-Butanone	0.690	10.6	7.31	19
Ethylbenzene	0.228	30.6	6.98	18
Acetone	0.665	7.8	5.21	13
2-Methylphenol	0.383	8.8	3.39	9
Phenol	0.241	11.2	2.70	7
Trichloroethene	0.217	8.7	1.88	5
Tetrachloroethene	0.135	12.2	1.65	4
Methylene Chloride	0.078	17.0	1.33	3
1,1,1-Trichloroethane	0.132	8.0	1.06	3
4-Methyl-2-Pentanone	0.117	9.0	1.05	3
Chlordane	0.255	3.6	0.92	2
Styrene	0.174	5.1	0.89	2
1,2-Dichlorobenzene	0.194	4.0	0.78	2
4-Methylphenol	0.113	5.6	0.64	2
2-Hexanone	0.195	2.8	0.54	1
Benzene	0.058	8.5	0.49	1
Naphthalene	0.027	13.4	0.36	<1
Bis(2-Ethylhexyl)Phthalate	0.021	15.2	0.32	<1

diminished concern in that regard. A wide variety of the prevalent organic constituents are persistent in the environment, are frequent groundwater pollutants and are shown to be present in such concentrations that, even with extremes of dilution, unacceptable concentrations could be expected to remain.

Some constituents, such as cadmium, mercury, endrin and lindane, have maximum contaminant levels (MCL) in drinking water in the low ug/l range.[10] Carbon tetrachloride, tetrachlorethene, trichloroethene, vinyl chloride and benzene have recommended maximum contaminant levels (RMCL) set at zero.[11] Aldrin, dieldrin, toxaphene and benzo(a)pyrene have ambient water quality criteria (AWQC) in the low ng/l range.[12] These compounds were detected a total of 1,192 times. The inevitable deterioration of drums and other waste containers constitutes a potential long term hazard to the groundwater resources of the nation.

Recent literature indicates that Volatile Organic Chemicals (VOCs) such as tetrachloroethene, trichloroethene and dichloroethene are biotransformed in groundwater to refractory compounds such as vinyl chloride.[13,14] Vinyl chloride exhibits nearly all of the Appendix A characteristics and is a particularly potent carcinogen. Vinyl chloride is being detected in groundwater which has been contaminated by the precursor VOCs noted above.[15] These VOCs and others were detected in more than 10% of the analyses, and one sample contained 82% trichloroethene.

The inorganic constituents identified are conspicuous because of the high frequencies of detection. Many of these elements may now be considered commonplace on hazardous waste sites. Again, depending upon the form in which deposited or leached, nearly all are threats to groundwater supplies. Metals such as mercury, lead, cadmium and chromium, in soluble compounds at very low concentrations, are potent long-term health hazards in groundwater.

The findings confirm the magnitude of the threat to groundwater supplies of deteriorating drums and tanks, leaking pits and ponds and leaking land disposal sites containing these chemicals. Moreover, they strengthen the likelihood that unknown, abandoned, improperly sealed and improperly closed disposal sites can be expected to continue threatening groundwater supplies for many years.

Significance for Field Investigators

While all of the characteristics of the priority pollutants are of general concern to the field investigator, those which are immediate, on-site hazards are of specific intense concern. These include immediate toxicity, ignitability, reactivity, corrosivity and severe irritation. Several of the chemicals found are extremely toxic, e.g., dinitrophenol, aldrin and TCDD (tentatively identified). Among the five most prevalent organics, four are ignitable. Maximum concentrations among the prevalent five ranged from 15 to 79%. Among the entire 133 organics, RCRA/CERCLA toxics were detected 3,997 times, ignitables were detected 7,739 times, reactives were present in 371 samples and severe eye and skin or respiratory irritants were present in 1,609 samples. 2, 3, 7, 8-TCDD was tentatively identified at low concentrations in 6 samples. Inorganic constituents, depending upon the species in which present, also constitute toxic, ignitability (e.g., elemental sodium), reactivity and severe irritant hazards. Cyanide was present in 33 samples. Thus, encounter with a material having one or more of these properties, is likely at any time a container on a hazardous waste site is opened. Moreover, since the CLP contracts do not require analyses for acutely toxic organophosphates or carbamates, their presence cannot be ruled out. There is no basis in these data, for any relaxation of the onsite safety procedures referenced earlier, particularly those dealing with opening and sampling of containers.

Significance in Packaging and Shipping of Samples

Considerations pertinent to packaging and shipment of suspected hazardous waste samples are essentially identical to those of the field investigator. These findings reinforce the 1979 and subsequent EPA Office of Health and Safety (OHS) guidance directing adherence to 49 CFR 172-173 requirements. The data further indicate the imperative that packaging be accomplished to preclude any possibility of leakage, breakage, or contact by incompatibles. OHS will shortly issue newly clarified "National Guidance for Complying with DOT Regulations in Shipping Hazardous Samples".

Significance for Laboratory Personnel

Managers, supervisors, analysts, and support personnel staffing laboratories that perform analyses on hazardous waste samples share the field investigator's concerns with the immediate hazards of toxic, ignitable, reactive, and irritant materials. If careless or inadequately trained, clothed or equipped, laboratory personnel may incur long-term risk from exposure to materials that are carcinogens or mutagens or that exhibit teratogenic, reproductive or severe irritant properties. A consideration of major operational significance is the prevention of contamination of work areas, equipment and instruments in environmental level laboratories.

The field investigator may find it necessary to deal with large quantities of waste while conducting sampling and other field operations. In contrast, since Agency practice has standardized around shipment of 8 oz sample containers, the quantity of material to which laboratory personnel may come into contact is significantly reduced. Leaks, spills, or ignition of such quantities of the waste materials identified herein, may be dealt with safely in a properly designed and operated hood. The findings herein support the concept that laboratory personnel, if properly trained, supervised, equipped and clothed, may perform operations incident to preparation of 8 oz waste samples for analysis without incurring risks beyond those assumed in normal environmental level laboratory operations. These findings do not provide a basis for relaxing safety rules or guidance or for attempting short cuts in laboratory protocols or procedures.

Table 5
Prevalent Inorganic Constituents

Constituent	Mean Concentration % $(\overline{X})$	Frequency Detected % (F)	$(\overline{X})(F)$	$(\overline{X})(F)$ Normalized to Silicon
Silicon	2.041	58.5	119.5	100
Iron	1.167	75.6	88.2	74
Calcium	0.571	63.6	36.2	30
Sodium	0.697	47.7	33.2	28
Aluminum	0.462	56.2	26.0	22
Potassium	0.311	66.6	20.7	17
Titanium	0.250	56.3	14.1	12
Zinc	0.152	72.1	11.0	9
Lead	0.213	49.4	10.5	9
Magnesium	0.115	60.5	7.0	6
Chromium	0.081	53.0	4.3	4
Copper	0.052	57.4	3.0	3
Barium	0.048	45.5	2.2	2
Manganese	0.016	63.8	1.0	1
Cyanide	0.030	2.8	0.08	<1

Many of the wastes (e.g., VOCs and heavy metals) present in environmental samples in high concentration can contaminate large areas of the laboratory and its personnel and equipment. Also, some of these pollutants are extremely toxic or present long-term hazards such as cancer or mutagenic change. For these reasons, the practice of using a modern, well equipped, separate laboratory for sample preparation should be continued.

CONCLUSIONS

Data from the organic and inorganic analyses of samples from drums and other containers, on hazardous waste sites throughout the nation, show the presence of priority pollutants, DOT and OSHA regulated substances, constituents having severe reproductive effects, severe irritants, carcinogens, mutagens, and teratogens, in significant numbers of identifications and in concentrations as high as 93%. These data indicate the magnitude of the threat to groundwater supplies of deteriorating drums and tanks, leaking pits and ponds and leaking land disposal sites containing these chemicals. They strengthen the likelihood that unknown, abandoned, improperly sealed and improperly closed disposal sites can be expected to continue threatening groundwater supplies for years to come.

The early procedural guidance, adopted by EPA, for the field investigation of hazardous waste sites and packaging of samples for shipment, is shown to be valid. The data confirm that laboratory personnel, working in a properly designed containment facility, if properly trained, supervised, equipped and clothed, may perform operations incident to preparation of 8 oz waste samples for analysis without incurring risks beyond those assumed in normal environmental level laboratory operations. A well designed, maintained and operated separate laboratory will provide the necessary protection from contamination of nearby or adjacent environmental level laboratories.

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SURVEY OF MOBILE LABORATORY CAPABILITIES AND CONFIGURATIONS

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INTRODUCTION

An essential element in the management of uncontrolled hazardous waste sites is analytical support service to determine the hazardous substances present, the extent of environmental contamination that has occurred and the effectiveness of any cleanup efforts that have been undertaken. Because of the variability in site location, the time lag in transportation of samples to off-site analytical facilities and the increased potential for compromise of sample integrity during transport, on-site analysis is an attractive alternative to the conventional practice of analyzing samples in a remote laboratory.

In this paper, the authors discuss their survey of existing mobile laboratory capabilities as they are applicable to emergency and remedial response situations. The discussion is focused on general design criteria, laboratory configurations, equipment and instrumentation and analytical protocols that have been used in existing mobile laboratories. The purpose of this project was to identify important factors that should be considered and evaluated when developing mobile laboratory capabilities for specific situations.

A computerized search was conducted for articles published since 1978 relating to the use of mobile laboratories for analysis of samples containing hazardous substances.[1-6] To ensure that the information contained in this report was current and to describe areas of interest where no pertinent material was found in the literature, the computer search was supplemented by personal communication with experts in the field representing either commercial firms or government programs. No assumptions were made or should be implied about the completeness or representativeness of the information so obtained.

INSTRUMENTATION

Both the instrumental configuration and the layout within the truck/trailer were found for various types of mobile laboratories. These were classified as either Rapid Response Vehicles or Real-Time Support Vehicles.

A Rapid Response Vehicle is defined as a compact mobile laboratory that can be used to determine the extent of a release, primarily in air or water. A mobile laboratory designed by Ecological Analysts, Inc. for the State of Maryland reflects this concept. The instrumental system, which incorporates an HP5880 gas chromatograph, was designed for air analysis but can be used to analyze sample extracts from other matrices. Calibrated standards are produced on board by a zero-air generator and gas blending equipment by Teledyne.

Real-Time Support Vehicles are designed to assess the level of contamination from a release and to provide field screening capabilities. Commercial mobile labs as well as the facilities used by the USEPA Municipal Environmental Research Laboratories, Oil and Hazardous Materials Spills Branch, Edison, New Jersey (MERL-Edison or MERL-OHMSB) fall into this category.

The commercial mobile laboratory is typically a vehicle with appropriate support systems and a selection of sophisticated instruments that varies with the needs of a particular situation. A listing of instrumentation used in selected commercial mobile labora-

Table 1
Instruments Used in Selected Commercial Mobile Laboratories

Firm*	GC	GC/MS	AA	HPLC	VOC	TOX	TOC	X-Ray Fluorescence	Chemiluminescence NOx Analyzer	UV/VIS Spectrometer
Alert	x		x		x		x	**		
EAL	x			x				x	x	
ES	x			x		x				x
ESE	x		x	x		x	x		x	
GCA	x									
IT	x	x†	x	x	x	x	x		x	x
OHM	x	x†	x	x††	x	x	x			x
Radian	x		x	x						
RTS	x		x	x						
SCA	x		x			x	x			

*Acronyms refer to the following companies:
**Will be used in a pending job.
EAL = EAL Corporation, Richmond, California.
ES = Engineering-Science, Arcadia, California.
ESE = Environmental Science and Engineering, Gainesville, Florida.
GCA = GCA Corporation, Bedford, Massachusetts.
IT = IT Corporation, Wilmington, California.
OHM = O.H. Materials, Findlay, Ohio.
RTS = Resource Technology Services, Inc., Devon, Pennsylvania.
SCA = SCA Waste Chemical Co., Inc., Cheektowaga, New York.
†Finnigan OWA GC/MS.
††Usage has been limited, but capability is present.

tories, as identified in this survey, is found in Table 1. Gas chromatographs (GCs) in mobile laboratories employ one or more of a variety of detectors: flame ionization detector (FID), thermal conductivity detector (TCD), photoionization detector (PID) and electron-capture conductivity detector (HECD). Identified brands and models of GCs used in commercial mobile laboratory applications are the Hewlett-Packard HP5840, Perkin-Elmer P-E 3920, HNU and Tracor Instruments Inc. Model 560. Many smaller instruments and pieces of equipment, such as the Miran® IR or bomb calorimeter, are also used routinely. The U.S. Coast Guard has successfully used a Fourier-transform infrared spectometer (FTIR) in response to an environmental incident.

A Canadian firm, Sciex Ltd., has developed instruments with mass spectrometric detector systems which can sample air directly, and, because of the short air-sampling and sample workup times, Sciex has begun manufacturing a mobile laboratory incorporating them. The van is available with either a TAGA™ 3000 GC/MS or a TAGA™ 6000 (GC) MS/MS system. Demonstrated uses of TAGA™ systems include the following: tracing the chlorine from a train derailment; determining PCBs in cement kiln stack gas, ambient air and soil; air monitoring at landfills for 20 compounds and in the workplace for bis (chloromethyl) ether; analyzing hazardous waste barrel contents; direct soil surface sniffing; hazardous waste emission monitoring; and continuous on-line monitoring of combustion gases and automobile engine exhausts.[7-9] Direct MS/MS analysis cannot be used alone when certain interferences are present.[8] In such instances, flash gas chromatography is used before MS/MS as a gross cleanup step.[8] The ionization sources for the TAGA™ 6000 are not completely effective in all situations, but the instrument has significant applications in many instances.[8]

CONFIGURATION, STRUCTURE, AND SUPPORT SYSTEMS

The effective operation of a mobile laboratory depends on its physical plant and support systems. Proper incorporation of such facilities as water supply, power, heating/ventilation/air conditioning (HVAC) and related equipment is of key importance.

In the summer, air should be cooled approximately 5 °F below the desired temperature, dehumidified and heated to the proper temperature to avoid furnishing makeup air at the dewpoint. A heating system comprised of resistance heaters of approximately 100 amps (@ 480 volts AC) can support a 78 °F temperature differential. A laminar flow from air diffusers improves fume hood performance by eliminating eddies in the system.

Mobile laboratory exhausts should be treated by passage through high efficiency particulate air (HEPA) and charcoal filters prior to release when the unit is used to analyze unknown or potentially hazardous samples. HEPA and/or charcoal filters may be necessary to treat the intake, depending on hazards present and location of the trailer. One hundred percent outside air must be used for all supply and makeup air; as many as 3 or 4 air conditioners may be required to furnish the 125-150 linear ft/min. face velocity required at the hood.

Power is usually obtained by tapping into a utility line or industrial plant source. The power requirement is about 100 kw (3-phase, 480-volt, 200-amps) for the MERL-Edison mobile laboratory and about 50-100 kw for commercial mobile laboratories. Power from utility lines or plant sources can be run through transient current suppressors to minimize surges. The mobile laboratories of most commercial firms have auxiliary generators for power in either emergency or remote situations. When not otherwise in use, mobile laboratories are generally "supplied with electricity" at the base laboratory, both to augment standard laboratory facilities and to be in a state of constant readiness for mobile use.

IT Corporation has built mobile laboratories for the USEPA (IERL-CI) and private firms and maintains the MERL-Edison mobile laboratory. Each laboratory is custom built for a predetermined purpose(s). The trailers preferred by IT are 45 ft long x 8

ft wide x 13.5 ft high, which allows inside dimensions of about 45 ft x 7.5 ft x 7 ft. This size provides sufficient space for ductwork, insulation and hood sashes.

The preferred suspension for a trailer is add-on air bag suspension. The IT design retains metal springs so that, in case of air bag failure, the trailer can be moved. A trailer with air bag suspension would greatly benefit from a tractor similarly equipped. IT shock-mounts instrumentation individually, while the MERL-Edison mobile laboratory has complete counter surfaces shock-mounted.

O.H. Materials' mobile laboratories are redesigned 42-ft box trailers with air-ride suspension. They contain the necessary glassware and equipment to support high volume extraction and/or digestions; 25 ft of chemically resistant countertop; safety features including a shower, eyewash stations and first-aid kits; two 5-ft fume hoods; storage capabilities for 250 gal of water; and six gas cylinders equipped with purification systems. The water purification system, consisting of ion exchange and carbon beds, supplies analytical grade water throughout the trailer.[10]

EAL has a 24-ft mobile laboratory with 119 ft² of effective floor space, air conditioning and two electrical generators (4 and 6 KW).

GCA's mobile laboratory is in a custom-designed 47.5 ft x 7.5 ft trailer. The laboratory consists of three main compartments: the hazardous materials handling laboratory, the gas chromatography laboratory and a utility room. All initial sample handling and aliquoting activities are conducted at the rear of the trailer, preliminary characterization and waste compatibility analyses are conducted in the middle of the unit and the more complex instrumental analyses are completed at the front of the unit. The laboratory sections contain collapsible tables and workspace to hold additional instrumentation, if needed. The utility room houses the ventilation hood blowers and filters, the air conditioning and the heating system and can be used for storage space, if required.

In some cases, mobile laboratories are equipped for communication by radio or telephone. MERL-Edison employs telefacsimile to transmit data electronically.

PROCEDURES AND PRACTICES

MERL-Edison

MERL-Edison has pioneered USEPA efforts to provide rapid on-site mobile laboratory analytical capabilities. In order to process the potentially large number of samples expected at release sites and/or to obtain timely results, many of MERL-Edison's mobile laboratory analytical procedures attempt to save time by modifying traditional sample workup procedures (e.g., APHA, ASTM, USEPA) and/or through use of more rapid instrumental determinative steps. The procedures at MERL-Edison are designed to minimize losses in precision and accuracy, to use less space and to generate less waste.

Traditional methods developed for lower levels of contamination in environmental matrices frequently involve extraction, evaporative concentration, chromatographic cleanup and other steps to remove interferences and concentrate the analyte for a reliable instrumental response. In spill responses, however, the analyte-to-interference concentration ratio is much higher and the identity of the spilled material is often known. Use of more rapid and direct sample preparation procedures and analytical methods is possible. For example, MERL-Edison has developed procedures for organics with a rapid extraction step, such as simply spinning the sample with the extraction solvent.[11-16] For certain situations, the extraction step has been completely omitted.[17] Streamlined cleanup techniques and use of positive displacement micropipets to eliminate multiple dilutions of samples and standards have also been adopted.[13,14]

MERL-Edison has not yet been requested to perform analyses to be used in litigation but has always concentrated on site characterization and the monitoring of remedial response efforts. However, standard analytical procedures are performed in the mobile

laboratory when it is located in Edison, New Jersey. This indicates that the laboratory is capable of generating high-quality analyses that can be used in litigation activities, provided support systems equivalent to those in Edison are available on-site. It is expected that this situation applies to all mobile laboratories now in use.

MERL-Edison is currently assembling a manual of their tested analytical protocols for mobile laboratory use that will be applicable to approximately 240 of the CERCLA hazardous substances in air, water or soil. The instrumentation required to perform the analyses includes GC/MS, GC/ECD or GC/HECD, GC/NPD, GC/FID, spectrofluorimeters, infrared spectrophotometers, emission spectrophotometers, carbon analyzers, inductively coupled atomic plasma emission spectrometers (ICP) and atomic absorption spectrometers (AA). In addition to providing field operation guidance for the instruments listed, each protocol provides guidance on sample isolation, fractionation, screening and the use of appropriate safety devices.

MERL-OHMSB has developed specific quality assurance protocols for use in mobile laboratory responses.[14] Several are designed to generate method validation data concurrently with sample results to give the on-site coordinator "real-time feedback" on analytical quality.[14,18] Use of a single standard to define the linear dynamic calibration range for a large number of compounds eliminates the need for extensive preanalysis instrument calibration.[13,14] A series of QA protocols that describes the preparation of synthetic samples for method validation has been prepared. These samples make use of media that resemble the site samples and include detailed instructions for fortification of samples with water-soluble, partially water-soluble, water-insoluble and volatile materials.[14]

Commercial Mobile Laboratories

Many commercial firms have designed their own mobile laboratory sampling, sample work-up and analytical methods. Typically, the same quality assurance procedures that are employed in the main laboratory are employed in the field units.[10]

Cost Factors

According to one firm which supplies both mobile and fixed-site laboratory services, the first two factors considered in setting a price for a mobile laboratory activation are how rapid a response is required and how many samples per day will be processed. If the mobile laboratory support effort is of sufficient magnitude, analytical costs may be lower than at a fixed-site laboratory. For example, an on-site compatibility screening (PCB, oxidant, reductant, cyanide and sulfide) of up to 200 samples per day was performed at a cost of approximately $15.00 per sample. Such large numbers of samples can help distribute the capital costs of mobilization. A two-day job would have prohibitive mobilization costs, while a stay of one to two weeks could be cost-effective. If laboratory trailers are located in several areas of the country, mobilization costs are greatly reduced.

STAFFING AND SAFETY

MERL-Edison staffs the mobile laboratory with highly trained, junior-level personnel because they are most agreeable to extended travel and long term mobile-laboratory duty. In order to coordinate the on-site work, senior-level scientists at the central laboratory receive raw data from the mobile laboratory via telefacsimile. After interpretation of the data, the central laboratory relays specific sample analysis procedures and corrective measures back to the mobile laboratory.[18] O.H. Materials staffs its mobile laboratory with highly trained chemists, while sampling and ambient air monitoring are performed by trained technicians.[10] A GCA case study mentions a four-man crew including a chemist.

An important part of a mobile laboratory set-up is the provision for safe working conditions for on-site personnel. MERL-Edison's sampling protocol requires screening of all samples for radioactivity with a Geiger counter before processing them. Any material identified as radioactive would be segregated and dealt with by radiochemical specialists. After the screening, all samples are handled in a glovebox and/or fume hood.

Private firms are responsible for training employees in proper sampling decontamination and hygiene procedures as well as for providing adequate protective clothing and respirators. In the laboratory, OSHA regulations as well as company-fostered safety procedures and precautions must be followed to maintain a safe working environment.

The mobile laboratory operated by O.H. Materials requires that trained personnel (e.g., chemists and technicians) determine necessary precautions before handling hazardous materials contained in sample containers. In addition to specifying safety procedures to be followed during sample collection and analysis, O.H. Materials also closely regulates the on-site work areas by designating exclusion (actual waste area), contamination reduction and support (non-contaminated) zones with access to these areas strictly controlled.[10]

CONCLUSIONS

In this survey, the authors found that mobile laboratories of varying degrees of sophistication have been used to conduct chemical analyses of environmental media. A full array of analytical instrumentation can be used in a mobile laboratory if the appropriate support systems are provided. Analysts have employed both standard and specialized procedures successfully.

Based on a limited number of past studies, mobile laboratories can produce analytical data equivalent in quality to fixed-site facilities. To routinely achieve such performance, appropriate quality assurance, safety and support systems must be available. As a consequence of on-site availability, analyses are completed much sooner in a mobile laboratory than in fixed-site facilities. This combination of performance capabilities and timeliness of results offer an excellent mechanism for obtaining analytical data during environmental responses.

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CONSTRUCTION OF A DATA BASE FROM HAZARDOUS WASTE SITE CHEMICAL ANALYSES

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INTRODUCTION

The legislative requirements of Superfund, coupled with the existence of huge amounts of sample-by-sample data for each hazardous waste site, make the creation of an Automated Data Base necessary to efficiently extract information from the mass of data. Section 301 of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)[1] provides that the President submit a comprehensive report to Congress on experience with implementation of this Act. As part of this report, USEPA must collect and analyze data on hazardous substances at Superfund sites. Two of the sources considered to be the most valuable for assessing the presence and extent of these substances are the data and information collected as part of the Hazard Ranking System (HRS) scoring process and the collection of analytical data from the Contract Laboratory Program (CLP). From these sources, USEPA will extract the following information:
- Sites where hazardous substances were present and where their abundance would pose a potential or actual hazard to health or the environment
- Rank of the hazardous substances according to the frequency of occurrence
- Measurement of the relative contribution of hazardous substances to the problem of hazardous substance releases

There are an estimated ten million pieces of information which could logically be included in a comprehensive data base. This demonstrates the need for a sampling approach to the information for the data base. Sampling has the benefit of acquiring useful data in the earliest stages of the data base development. This, in turn, decreases the amount of time needed for development and, consequently, decreases the cost of the data base.

DATA BASE DEVELOPMENT

Objective of Sampling Data to Develop a Data Base

A constraint on the computerized data base was to select and automate enough data to characterize hazardous waste sites from the CLP data and not to characterize the total data available. The CLP data contain sample results which are indicative of site composition. They also contain quality control (QC) samples, laboratory blanks and field blanks, as well as up-gradient and down-gradient samples. Incorporation of the QC samples into the data base would lead to a bias in the site characteristics. This precludes use of a random selection of samples. A random method would not decrease relative number of samples selected which are not field samples.

CLP Routine Analytical Services Repository

There are samples from over 1,200 sites in the CLP Routine Analytical Services (RAS) Repository. Two-hundred thirty-one of these sites are on the NPL. RAS samples can be classified by the matrix (soil or water) and the type of analysis (organic or metal). The matrix was not taken into account in selecting samples. The RAS analytical data have not been previously automated.

The development strategy of the CLP Data Base has precluded any specific intended use of the data. Thus, it has tended toward the accumulation of a true "data base." Also, the data were not collected using a particular mathematical or physical construct or model beyond sampling plan methodologies. Therefore, they were not constrained by the use of a particular model. The CLP data have the following conditions associated with them:
- The data were collected in and around hazardous waste sites with the objective of detecting hazardous waste components that were in or leaving the suspected site
- While the universe of chemicals may be considered, the most readily identified, quantified and validated compounds detected are the so-called 133 organic compounds plus metals described as Priority Pollutants
- These data represent analytical results and not manifests, interviews from the site history or on-scene monitoring

The Automated Data Base is comprised of results taken from a random selection of 30% of the sites for which the CLP had collected data. The selection process was constrained by the condition that 10% of these sites would be NPL sites.

DESCRIPTION OF ANALYTICAL DATA SOURCES

A sample is physical evidence collected from a hazardous waste site, the immediate environment or any related source. All samples collected at one site during a predetermined and finite period of time were grouped into a Case and were assigned a Case Number by the Sample Management Office (SMO). The Case Number provides a unique identification for all relevant documentation.

Organic Analysis Data Package

The Organic Analysis Data Package contains at least four packages: an Organic Sample Data Package for each sample in the Case; an Organic QC Package (blank/duplicate/spike); an Organic Sample Data Summary Package; and an Organic Standards Data Package. All reports and required documentation are identified

with the respective SMO Case No. and associated Sample No. and Traffic Report numbers.

The analysis summaries in the Case Folders (described below) were used as the source for the Automated Data Base. The Organic Sample Data Summary Package includes: organic analysis data sheet(s); tabulated results of analyses of specific compounds required by the contract and tentatively identified compounds (TIDs) from the Organic Sample Data Package; and surrogate spike, matrix spike, duplicate and blank analyses from the Organic QC Package. This summary provides the organic analysis data for the analytical data base and is filed in the readily accessible SMO Case Folder.

Inorganic Analysis Data Package

This data package includes, for each Case, the tabulated results of inorganic analyses. The data package includes: the analytical results for waste and extract spikes, duplicates, standards and blanks; instrument calibration data; and procedural/method blank results.

Case Folder

A Case Folder represents the sample-by-sample results for a site over a finite period of time. The Case Folders are organized in ascending Case Number sequence. A Case Folder contains the following:
- Traffic Report forms for each organic, inorganic and/or high hazard sample in the Case
- Tabulated analytical results for all organic and metals determinations
- All other relevant sampling documentation and correspondence

ANALYTE OCCURRENCE

The number of samples needed to detect in the data base whether a pollutant was found at a site is a function of the number of positive samples for that pollutant at the site. In the following relationship:[1]

$$F = 1 - (1 - P)^n \qquad (1)$$

P is the proportion of positive samples from the site and F is the probability of getting at least one positive sample out of n randomly selected samples. Six samples selected randomly from the CLP data for a site would be sufficient to detect substances at sites where at least half the samples were positive for a given hazardous substance. There is a 98% chance that at least one of the six samples would show a positive result. This probability, combined with resource constraints, led to the inclusion of six determinations of each pollutant at each site.

Possible false positive results point to the need to establish a minimum concentration below which the presence of the pollutant is not convincingly demonstrated. Before a sample may be considered positive from a hazard standpoint, the significance of occurrence of compounds at or below specified indices (i.e., water quality limits) may need determination. The number of samples (n) needed to estimate the average concentration at a site with 95% chance of making an error no greater than E% of the true value is:[1]

$$n = 4 C^2/E^2 \qquad (2)$$

where C is a measure of random between-sample variation as a percentage of the true concentration expressed as the coefficient of variation for the site. The values of n generated for different values of E and C^2 are given in Table 1. For example, six organic samples may be sufficient if a 50% estimation error in concentration is acceptable for a site.

DATA ENTRY PROCESS

The data entry process is initiated when a completed Case Folder is received. The Case Folders are first reviewed by a pre-entry

editor. This edit is verified and the Case Folder, if ready for entry, is given to a Data Entry Operator for further processing. A post-entry editor checks for errors. When all errors have been rectified, the information is entered into the system and merged into the Master File.

Pre-Entry Edit and Validation

The pre-entry editor initiates the data entry process. The pre-entry editor: (1) checks the physical contents of the Case Folder for completeness; (2) correctly identifies, names and lists all samples in the Case to be included; (3) locates and identifies tentatively identified compounds and flags all compounds not identified in our Chemical Compound Nomenclature List (CCNL) for resolution or updating; (4) records all relevant administrative data (sampling, analysis dates, etc.); (5) selects a matrix code; (6) reviews the analytical data for each sample; and (7) flags and resolves any data reporting problems. If analytical and/or administrative data are missing, the folder is retained until the missing information is located.

Table 1
Values of n Generated by Eq. 2

Coefficient of Variation (C)	Percent Error (E)	
	25	50
25	4	1
30	6	2
50	16	4
60	23	6

If a compound cannot be identified, it is noted and filed on an Unknown Compound List. Provisions are being made to enter such compounds in general categories under the rules set by the Chemical Abstracts Service. The Chemical Nomenclature File currently holds entries for approximately 1,274 organic and inorganic substances.

Sample Selection

Samples were selected systematically from a Case, excluding QC samples, with the following assumptions:
- For sites having data in more than one Case, the first Case contains the most representative samples and results of site constituents
- The general usefulness of the Automated Data Base will be enhanced by including data from a larger number of sites

The data sampling procedure consisted of systematically selecting a fixed number of samples from 30% of CLP sites. If a selected number of sites in the Automated Data Base exhibited a great amount of variation from the total data for this site, additional samples would be added on a site-by-site basis after the initial stage of data base development. Program resources allowed for automation of the results of 10 samples for each of the 358 sites selected.

Organic Compounds

The samples within a Case are aligned in ascending numerical order. The first and last samples are selected as well as every nth sample where n is a multiple of the N/5th sample (N being the total number of samples in the Case). When a QC sample is selected, the lower adjacent sample is selected in its place. If the first Case does not contain enough samples, the second Case is sampled using the same method, the nth sample being the multiple of N/(k-1) where k equals the number remaining to be sampled.

Metals

The method of selection is identical to that of organic samples except that k for the first Case is 3.

Verification Rationale

The approximation of a model requiring random selection of samples (Eq. 1 and Eq. 2) to a systematic selection required verifying the correspondence of the Automated Data Base with the CLP Repository from which the data was drawn.

A sample requires fewer resources to assemble a data base but runs a greater risk of not adequately representing the data on a site basis. Too large a sample would assuredly give a good representation but it would unnecessarily tax resources and necessitate sampling a smaller number of sites. Comparing the CLP data and the site data included in the Automated Data Base gives a qualitative evaluation of the correspondence between the two distributions. The criterion for correspondence of the data base with the CLP data was the correlation of the site-by-site frequency distribution of compounds in CLP data to the frequency distribution of compounds in the Automated Data Base.

The degree of correspondence of the Automated Data Base to the site inventory must be quantified so that the sampling procedure can be validated. The distribution of compounds obtained by sampling the CLP data on a site-by-site basis should be proportional to the distribution that exists in the CLP Repository. The correlation coefficient of the linear function defined by the comparison of the frequency distribution of the CLP inventory with the data base sample distribution should be a quantitative measure of the degree to which the data base characterizes the site data. It is, therefore, an indirect evaluation of the sampling procedure. If the samples in the data base exactly replicated the distribution in the CLP site inventory, the line described by the points would be a straight line of slope, M = 1, through the origin. Computation of the correlation coefficient quantifies the degree to which the Automated Data Base describes the data inventory for the site in the CLP data.

RESULTS

Histograms of the frequency of compound detection for a particular site are shown in Figure 1. The lower histogram is the frequency distribution of detection for all the CLP data for the site. The upper histogram is the distribution for the results incorporated into the data base.

A typical plot of the frequency distribution of the percent abundance of the Automated Data Base versus the percent abundance in the CLP Data Base for a particular site is given in Figure 2. Each point in Figure 2 represents the percent of samples that are positive for a particular compound. The X coordinate represents the percent in the CLP site inventory and the Y coordinate represents the percent of positive results from the sample taken for the data base. Positive results are restricted to certain percentages as a function of the number of samples taken; i.e., for six samples the only possible percentages are 0, 17, 33, 50, 67, 83 and 100.
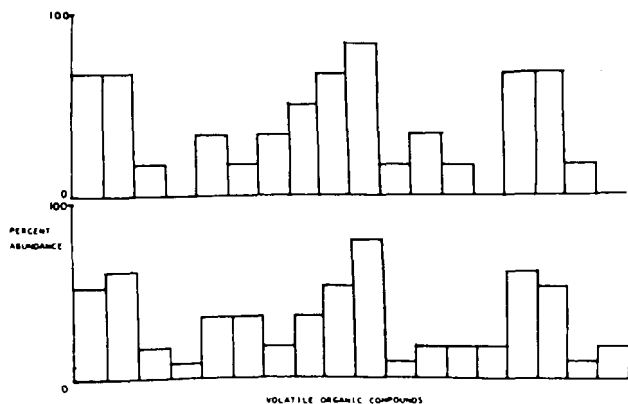
Figure 1
Frequency Distribution of Compound Abundance in a Site Inventory for VOA Data (Bottom) and Corresponding Distribution in the Data Base (Top)
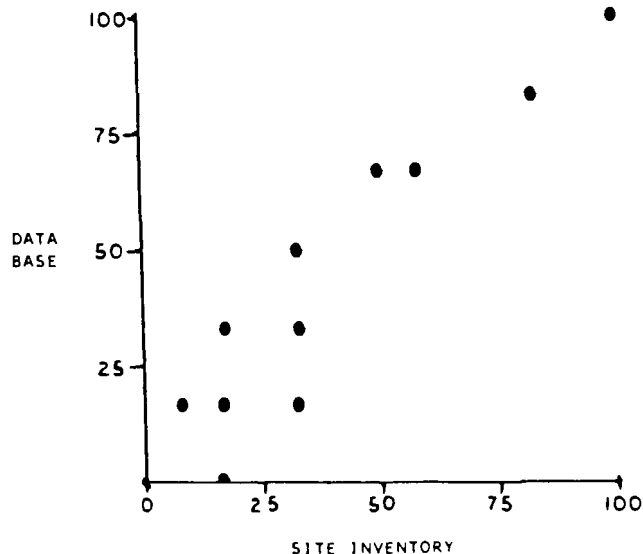
SITE INVENTORY
Figure 2
Automated Data Base
Site Data vs. CLP Site Data (Volatiles)

Tables 2 to 5 contain the correlation coefficients obtained by the sampling procedure described and by introducing modifications to the sampling procedures as described below:
- CLP refers to the described systematic procedures
- Random refers to random selection of samples using fixed numbers (six organic and four metal samples)
- Proportional by Case/Random by Sample refers to weighting the number of samples selected from each Case as a fraction of the relative number of samples from each Case. The conditions indicate results for a fixed number of samples and fixed percentages of total samples
- Proportional by Matrix/Random by Sample, using fixed number and fixed percentage, refers to a random selection of samples from each matrix regardless of Case. Samples are selected in numbers proportional to their matrix representation in the site data.
- Augmented by Case refers to addition of six organic samples and four inorganic samples proportionately by Case to the described systematic procedure; used where original single Case sampling had been done on multi-Case sites.

Examination of the data in Tables 2 to 5 verifies that the proposed sampling procedure is adequate to obtain representative data for sites of three Cases (sampling episodes) or less. The correlation coefficient between the Automated Data Base and the CLP site inventory becomes less positive when more than three sampling episodes occur at a site. Use of a Case-weighted sampling improves the correlation between the CLP Repository and the Automated Data Base. The great majority of sites exist in the CLP Repository as less than three Cases, and therefore, the systematic sampling scheme from the initial Case will suffice for the bulk of the CLP data sampled.

As a practical matter, the correlation coefficient of total data to sampled data from each site cannot be determined. This would be equivalent to entering all data into the CLP Automated Data Base. It was necessary to augment the sampling of certain sites where more than three Cases of data were in the CLP Repository. The correlation coefficients for the augmented data to previous methods are compared in Tables 6 and 7. Overall correlation to the total site data was improved over the single Case sampling method. This augmented method helped to maintain consistency of operation with the original sampling scheme.

It is interesting to speculate on the physical interpretation of the intercept and the slope of the line defined by the frequency distributions of the site inventory and the Automated Data Base sample. The intercept would be non-zero if the X or Y coordinate of each point had a constant percentage of positive values added to or sub-

Table 2
Site Data Characterization for Small (less than 3 Cases) Sites
Organic Compounds

Site	No. of Data Points	Correlation Coefficients	Slope	Intercept
Wildcat Landfill	18	0.79	1.62	−7.24
Toms River	42	0.91	1.12	3.06
Mason County	27	0.86	0.91	3.29
Marion City	14	0.86	0.90	−2.25

Mean/Median Correlation Coefficients
Organic - 0.86/0.86

Table 3
Site Data Characterization for Small (less than 3 Cases) Sites
Metals

Site	No. of Data Points	Correlation Coefficients	Slope	Intercept
Wildcat Landfill	18	0.92	0.85	18.54
Mason County	17	0.58	0.94	−9.36
Marion City	11	0.73	1.31	−5.64

Mean/Median Correlation Coefficients
Inorganic - 0.74/0.73

Table 4
Site Data Characterization by Single Case (Old) Sampling and
Multi-Case (New) Sampling
Organic Compounds

Site	No. of Cases	No. of Data Points	Correlation Coefficients (Old/New)	Slope (Old/New)	Intercept (Old/New)
Old Mill	4	73	0.73/0.84	0.76/1.06	−4.07/−0.73
Indian Bend Wash	6	20	0.73/0.97	0.49/1.30	−3.31/−2.79
Envirochem	5	52	0.52/0.61	1.12/0.71	12.7/0.75
Andover Sites	4	24	0.53/0.87	1.24/1.68	1.66/−4.18
Acme Solvents	4	56	0.76/0.90	0.68/1.25	9.39/0.67
Niagara Frontier	4	39	0.91/0.88	1.63/0.86	−4.24/−2.64
Kingston, NH	5	68	0.69/0.89	0.95/1.06	−2.00/−1.70

Mean (Old/New) - 0.70/0.85
Median (Old/New) - 0.73/0.88

Table 5
Site Data Characterization by Single Case (Old) Sampling and
Multi-Case (New) Sampling
Metals

Site	No. of Cases	No. of Data Points	Correlation Coefficients (Old/New)	Slope (Old/New)	Intercept (Old/New)
Old Mill	3	22	0.84/0.90	1.22/0.82	−15.7/−9.06
Indian Bend Wash	6	20	0.49/0.36	0.81/0.57	−7.18/3.40
Envirochem	3	21	0.50/0.88	0.64/1.05	22.9/7.22
Andover Sites	3	16	0.72/0.95	1.02/1.00	−0.74/−9.02
Acme Solvents	2	12	0.97/0.92	1.02/0.92	−3.84/−0.68
Niagara Frontier	2	16	0.97/0.95	1.13/0.91	−1.16/−12.5
Kingston, NH	4	21	0.42/0.89	0.55/1.15	30.0/−8.83

Mean (Old/New) - 0.70/0.84
Median (Old/New) - 0.72/0.90

Table 6
Comparison of Correlation Coefficients for Large
Multi-Case Sites
Organic

Site	Original Systematic	Proportional by Case/ Random by Sample	Augmented Proportional by Case
Old Mill	0.73	0.84	0.89
Indian Bend Wash	0.73	0.97	0.83
Envirochem	0.52	0.61	0.76
Andover Sites	0.53	0.87	0.78
Acme Solvents	0.76	0.90	0.93
Niagara Frontier	0.91	0.88	0.90
Kingston, NH	0.69	0.89	0.78
Mean	0.70	0.85	0.84
Median	0.73	0.88	0.83

Table 7
Comparison of Correlation Coefficients for
Large Multi-Case Sites
Inorganic

Site	Original Systematic	Proportional by Case/ Random by Sample	Augmented Proportional by Case
Old Mill	0.84	0.90	0.91
Indian Bend Wash	0.49	0.36	0.84
Envirochem	0.50	0.88	0.84
Andover Sites	0.72	0.95	0.87
Acme Solvents	0.97	0.92	0.98
Niagara Frontier	0.97	0.95	0.97
Kingston, NH	0.42	0.89	0.64
Mean	0.70	0.84	0.87
Median	0.72	0.90	0.86

tracted from it. This would indicate a bias in the subset of samples included in the Automated Data Base. The slope of a subset of samples which has a frequency distribution identical to the CLP site inventory would be equal to 1. To the extent that the slope changes from 1, the characterization becomes a proportionality. Slopes less than 1 may indicate an under-representation of positive

The correlation of the frequency distribution of positive occurrences with the frequency distribution obtained from a systematic sampling of the first Case may have some inferences with regard to the cost/benefit of subsequent sampling of hazardous waste sites. Frequency distributions indicate that the sites are no better characterized with respect to compounds present in two or three Cases than in the first collection of samples. This conclusion disregards other objectives of subsequent site visits in connection with sampling such as determining the extent of contamination.

ACKNOWLEDGEMENTS

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APPLICATION OF MOBILE MS/MS TO HAZARDOUS WASTE SITE INVESTIGATION

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INTRODUCTION

In recent years, application of the MS/MS technology has been advanced significantly in the areas of air monitoring and dioxin analysis. In both applications, the technique offers advantages that are unparalleled by conventional modes. Specifically, the technique offers real-time analysis; detection, identification and quantification at very low levels; and high specificity. Results of both types of applications are discussed in this paper. This discussion, however, is preceded by some details of the instrumentation.

INSTRUMENTATION

MS/MS has recently emerged as an analytical tool. The instrument consists of two quadrupole mass analyzers separated by a third quadrupole operated in a total ion mode. By introducing a collision gas in the domain of the middle quadrupole, the ions emerging from the first mass analyzer are fragmented, and the fragments are analyzed in the second mass analyzer. The instrument can be operated in various modes. In a single mass analyzer mode, the instrument is used to scan all ions produced by the source (parent ions). In the tandem MS mode, the instrument can be set to transmit preselected parent ions through the first mass analyzer, fragment the selected parent ion in the region of the middle quadrupole and analyze the produced fragments in the second mass analyzer, thus producing characteristic mass spectra that are used in the identification of components. Alternatively, the second mass analyzer may be set to monitor a specific fragment ion (daughter ion). In the last two applications, the first mass analyzer acts as a mass separator, thus eliminating the need for chromatographic separation.

Because the fragmentation pattern of molecules is a unique characteristic, the combination of specific parent ion and daughter ion offers high specificity in the analysis. When this combination is not sufficiently unique, monitoring one parent ion in tandem with two daughter ions supplies the additional specificity.

Two ionization sources are currently in use. Both employ chemical ionization. This mechanism of ion formation is such that the parent ions formed are more readily related to the compound being analyzed than is the case when electron impact is used. The dominant mechanisms of ion formation are charge transfer and proton transfer, but with little or no fragmentation of the parent ions at the source. Hence, the molecular weight of the neutral compound is readily determined when chemical ionization is employed. The two sources that are employed in the field are described below.

The Atmospheric Pressure Chemical Ionization (APCI) Source

In the APCI source, the principal components of air are ionized by a corona discharge, forming initially the ions N_2^+ and O_2^+. These energetic ions rapidly undergo collisional moderation and through reaction and charge transfer form hydrated protons $H^+ \cdot (H_2O)_n$, where n is a whole number. The hydrated protons, in turn, are responsible for the ionization of the trace components. This ionization usually is in the form of proton transfer, so that the parent ion is in the form TH^+, displaying an apparent molecular weight 1 amu larger than the true molecular weight. In addition to the parent ion of the form TH^+, hydrated parent ions are also formed. These ions are of the form $TH^+ \cdot n(H_2O)$, where n is a whole number. The appearance of clustering is a function of the moisture content of the sample. In spite of the appearance of more than one parent ion, however, the recognition of clusters is made easy by virtue of their exhibiting a series of daughter ions that are formed by a neutral loss of 18 amu, corresponding to the sequential loss of water molecules.

Trace compounds that are amenable to ionization by this technique are those with high proton affinity, characteristically oxygenated and nitrogenated compounds. Selectivity in the ionization mechanism is obtained by introducing into the air stream a reagent gas, such as ammonia, which has a proton affinity higher than that of water. If ammonia is used as a reagent gas, the principal ionization source will be the ammonium ion, NH_4^+, and trace amines in the air stream will be preferentially ionized without interference from the oxygenated compounds.

The Chemical Ionization (CI) Source

Initial ionization in the CI source is similar to that which occurs in the APCI source, forming the ions N_2^+ and O_2^+. The CI source, however, is operated at reduced pressure, typically 0.3 torr. Thus, collisional moderation of the very energetic ions is reduced, and the principal ionizing medium is NO^+, which is formed by reaction between the initial ions and neutral oxygen and nitrogen. Ionization of trace components occurs through several mechanisms principally charge transfer, forming a parent ion T^+ with a mass equal to the molecular weight of the neutral trace compound or by proton abstraction forming the ion $(T - H)^+$ with a mass 1 amu less than that of the neutral parent compound. Additionally, the presence of moisture in the air would lead to ionization reactions similar to those occurring in the APCI source. Clustering leads to parent ions of the form $T \cdot NO^+$. In the case of chlorinated compounds, loss of chlorine or hydrogen chloride may occur at the source.
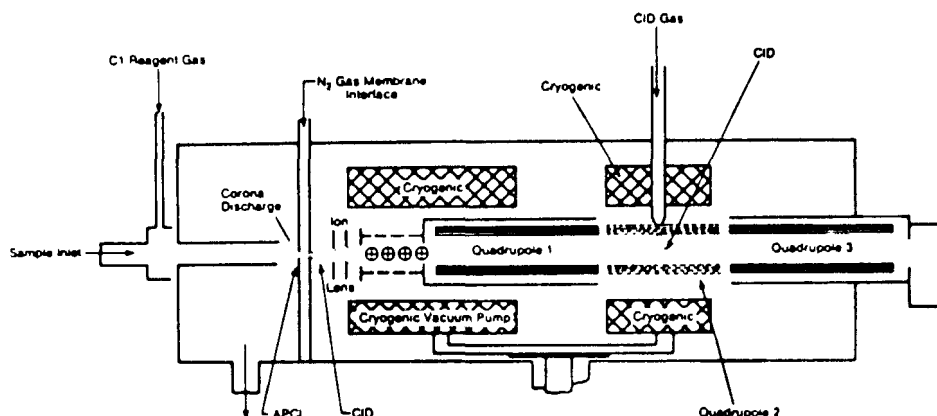
Figure 1
A Schematic Representation of THAT TAGA™ 6000 MS/MS

While the complexity of the source chemistry complicates the interpretation of the results, the Cl source provides a means for direct analysis of aromatic compounds, the alkenes and chlorinated compounds.

The design of the instrument is shown in Figure 1.

APPLICATIONS TO AMBIENT AIR ANALYSIS

The existing conventional methodologies for the detection of low levels or organics in ambient air require that the compounds be adsorbed onto a substrate over a finite period of time. The substrate is then taken for analysis in an off-site laboratory where the compounds are either thermally desorbed or solvent eluted from the substrate and analyzed by GC or by GC/MS. The technique suffers from several drawbacks:

- The process is time consuming, producing results several days or weeks after the sampling has been performed.
- Obtained quantitative results are always time-averaged over the duration of the sampling period. Temporal fluctuations cannot be obtained by this method.
- The desorption process for the determination of the components collected introduces uncertainties. Certain compounds are adsorbed so strongly that they cannot be recovered from the substrate. Other compounds may undergo reactions or rearrangements so that they are misidentified in the recovered eluate.

These difficulties are minimized or eliminated by employing the on-site MS/MS instrument mounted in a van and operable both in a stationary mode and a mobile mode. The specific advantages are:
- Analysis is in real time.
- Quantitation is performed so that temporal fluctuations are obtained, yet time-weighted average concentrations can also be derived from the data.
- Alteration of the components of air is minimized.
- Wall effects are reduced by maintaining a very rapid air flow through the system, typically 2l/sec.
- The instrument is capable of performing analyses of extremely polar compounds.

The instrument has been employed in the mobile mode in several studies. Two of these studies are presented here.

Abandoned Hazardous Waste Sites

In the first study, the mobile laboratory was called upon to qualitatively determine trace components in the air and quantitatively determine specific target compounds. The site under consideration had been abandoned by its owners, closed, and at the time of the study was in the process of being cleaned up. The site contained an incinerator, several ash piles, waste lagoons and drums.

Several areas of the abandoned site were investigated qualitatively using both the APCI source and the CI source. Without attempting to identify components, a single MS scan was taken off-site and upwind of the site so that the total ion spectrum of the ambient air could be obtained. The total ion spectrum was used as a reference. A total ion spectrum was taken repeatedly at various locations on-site. In each case, the reference scan was subtracted from the new scan, and the masses of components that were absent in the background were subjected to MS/MS analysis. The first mass analyzer was set to transmit one parent ion at a time, and the second mass analyzer was set to analyze and record the fragmentation pattern. The background subtracted total ion scan is shown in Figure 2 while the resulting mass spectrum of a single component is shown in Figure 3. The compounds that were identified at this site are listed in Table 2.
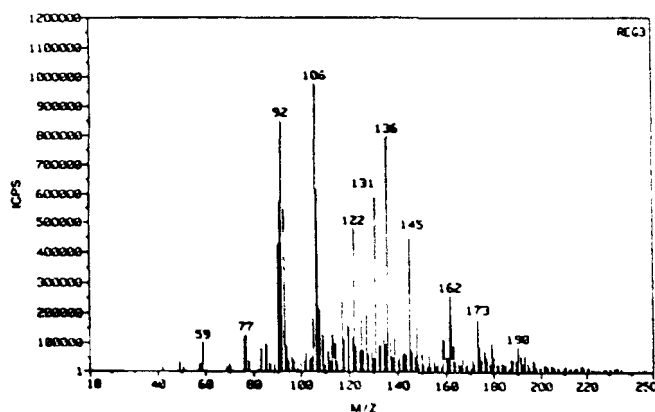
Figure 2
Background Subtracted Single MS Scan of Air Above a Sludge Pile

Quantitation was performed for specific target compounds. To establish method equivalency, the MS/MS technology was employed side-by-side with conventional NIOSH charcoal tube sampling. A typical single component calibration curve is shown in Figure 4. Because quantitation was to be performed alongside charcoal tube sampling, the mobile laboratory was stationed in one location.

Activity on the site, however, created fluctuations in the concentration of the target compounds. The effect is shown in Figure 5. A summary of the time-weighted average concentrations of the target compounds obtained by the two methods is given in Table 2. The data clearly demonstrate the equivalency of the two methods;
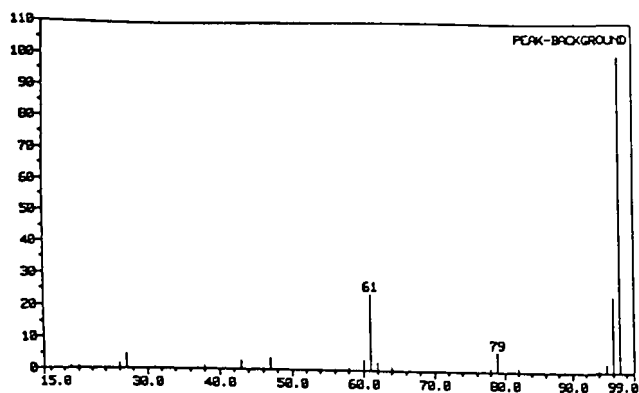
Figure 3
Normalized MS-MS Scan of M/Z = 97 from either
Trichloroethane or Dichloroethylene
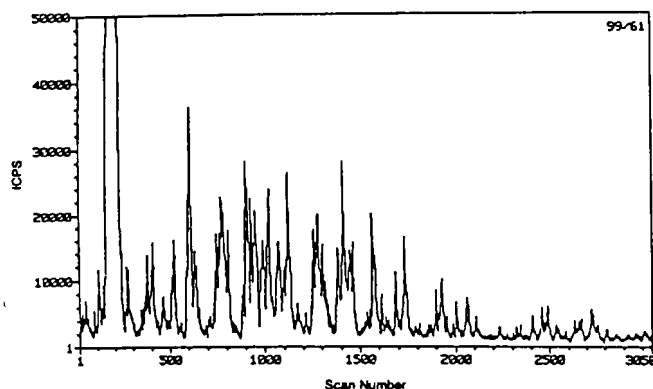
Figure 5
Time Dependent Measurements of the Concentration
of 1,1,1-Trichloroethane

Table 1
Compounds Identified at Abandoned Site Using MS/MS Technology

Compound	Source	Molecular Weight	Parent Ion m/z
Formamide	APCl	45	46
Acetone	APCl	58	59
Acetamide	APCl	59	60
Propanol	APCl	60	61
Ethylene glycol	APCl	62	63
Methyl ethyl ketone	APCl	72	73
N,N-Dimethylformamide	APCl	73	73
Butanol	APCl	74	75
Dimethylsulfoxide	APCl	78	79
Pyridine	APCl	79	80
Methylene chloride	Cl	84	83
or chloroform		118	83
N,N-Dimethylacetamide	APCl	87	88
Aminobutanol	APCl	89	90
Toluene	APCl	92	91
Aniline	APCl	93	94
Dichloroethylene	Cl	96	96
or trichloroethane		132	96
Methyl isobutyl ketone	APCl	100	101
N-Hydroxy-1,2-ethylene- diamine	APCl	104	105
Diethylene glycol	APCl	106	107
Xylene	Cl	106	106
Chlorobenznene	Cl	112	112
N,N-Diethylacetamide	APCl	115	116
Butyl Cellosolve	APCl	118	119
Trichloroethylene	Cl	130	130
Trichlorofluoromethane	Cl	136	101
Dichlorobenzene	Cl	146	146
Tetrachloroethylene	Cl	164	164

Table 2
Comparative Results from MS/MS and Conventional Analyses

Compound	Mean Concentration, ppm (v:v)	
	MS/MS Method	NIOSH Method
Methylene chloride	3.4	3.7
1,1,1-Trichloroethane	1.4	1.7
Trichloroethylene	1.8	1.1
Tetrachloroethylene	0.2	0.25
Chlorobenzene	0.04	Not detected
Toluene	0.7	0.5
Xylene	0.5	0.29
Methyl isobutyl ketone	0.005	Not detected
Acetone	0.017	Not detected

however, the results from the MS/MS quantitation were available on the same day, while the results from the charcoal tube quantitation became available two months after the samples were collected.

Ambient Air Analysis in the Vicinity of a Sewage Treatment Plant

In this study, attempts were made to identify disagreeable odors that pervade a residential area. The location of the study is a heavily industrial area, interspersed with residential sections.

Odor incidents have been reported under certain meteorological conditions, usually in the summer. Previous studies and inspections have indicated that the odor is very intense in the vicinity of the sewage treatment plant (STP). The goal of this study was to identify the odorous components and to attempt to isolate what industrial clients of the STP might be contributing to the odor problem.

During the period of the study, there was no odor incident, although the odor was very intense in the immediate vicinity of the treatment plant. In this study, all measurements were done from public access roads.

The industrial nature of the area and the constantly shifting winds made it difficult to determine a baseline background. Because of the industrial background, the reference scan for this study was obtained with "zero air" distilled from liquified air and presumably containing only the principal components of air. A large number of compounds was identified, although it is not known whether any of them contributed to the odor. The compounds identified and a notation showing whether they appear downwind of industries that may be contributing through their
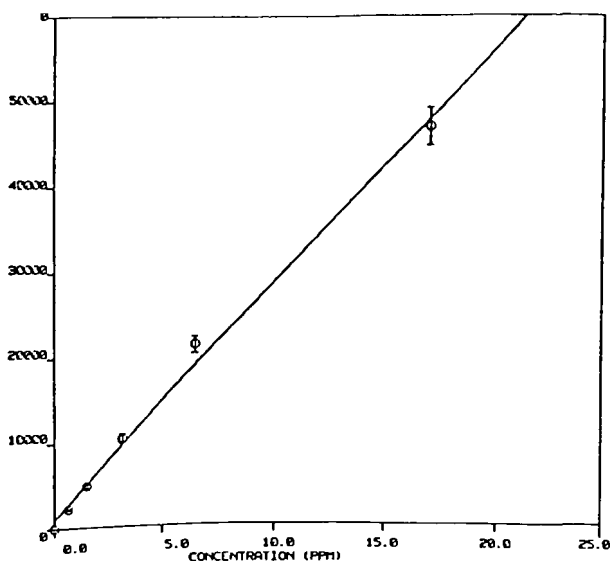
Figure 4
Calibration of 1,1,1-Trichloroethane Parent/Daughter Ion = 99/61

Table 3
Summary of Identified Compounds

Compound	Molecular Weight	STP Upwind	STP Downwind	Ind. A	Ind. B	Ind. C
Ammonia	17	X	X	X	X	
Methanol	32	X	X	X	X	
Hydrogen sulfide	34	X	X			
Acetonitrile	42		X		X	
Ethanol	46	X	X	X	X	
Acetone	58	X	X	X	X	X
Propylamine	59		X	X	X	
Propanol	60					X
Dimethyl sulfide	62		X	X	X	
Ethanethiol	62		X		X	
Ethylene glycol	62		X	X	X	
Methyl ethyl ketone	72	X	X	X	X	X
Butanol	74	X	X	X	X	
Propanediol	76		X	X		X
Benzene	78		X		X	
Methylene chloride	84		X		X	
Pyrrolidone	85				X	
Thiazole	85				X	
Methyl acrylate	86		X		X	X
Butyric acid	88				X	X
Toluene	92		X		X	
Methoxyfuran	98		X	X	X	
Methylthiazole	99		X	X	X	
Methyl isobutyl ketone	100				X	X
Propyl acetate	102				X	X
Hexanol	102				X	X
Xylene	106		X	X	X	
Diethylene glycol	106				X	X
Chlorobenzene	112		X		X	
Octanol	130		X		X	
Dichlorobenzene	146		X		X	
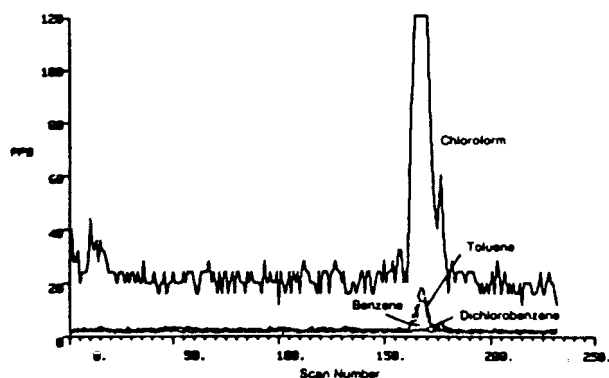
Figure 6
Mobile Monitoring for Benzene, Toluene, Chloroform and Dichlorobenzene around Sewage Treatment Plant
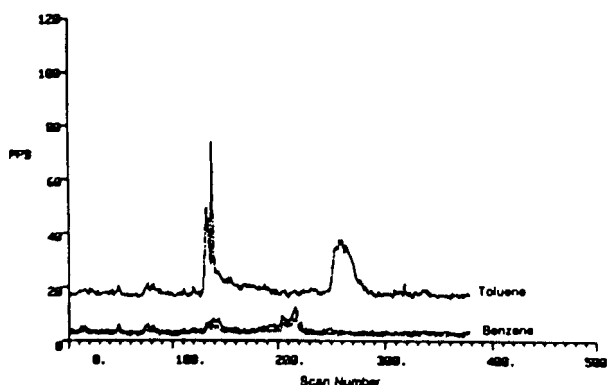
Figure 7
Mobile Monitoring for Benzene and Toluene around Industry B

waste to the plume emanating from the STP are shown in Table 3. Although a strong correlation between the composition found at the STP and that found at Industry B appears, additional analyses are needed before a stronger tie can be established.

Because of the possibility of contribution of compounds from several sources, mobile monitoring for target compounds was performed. The principal target compounds were benzene, toluene and dichlorobenzene. Around the STP, the compounds peaked simultaneously (Figure 6). The peaking at Scan No. 167 occurred exactly downwind of the STP, with no potential sources between the van and the STP.

A similar mobile monitoring was performed around Industry B (Figure 7). Simultaneous peaking is observed at Scan No. 140, indicating that at least in part the compounds of interest occur simultaneously. However, additional sources of the compounds are also indicated.

Concentrations and detection limits for several target compounds were determined (Table 4). The reported detection limits are as measured in the field. Lower detection limits can be obtained if the instrument is optimized for the specific target compound.

APPLICATION OF MS/MS TO DIOXIN ANALYSIS

In the past two years, considerable effort has been expended to develop the application of MS/MS technology to dioxin analysis. To facilitate efficient use of the instrument, both sample preparation and chromatographic separation had to be modified drastically. Because of the high specificity of the MS/MS technique, it was hoped that the extensive sample preparation that is currently required by the USEPA method could be reduced to much simpler procedures. The high sensitivity of the instrument made it possible to perform the analyses on extracts without the need for preconcentrating.

The method consists of single-step extraction, extract clean-up when needed, flash chromatography and MS/MS detection. A schematic diagram of the method is shown in Figure 8.

Experience with Missouri soils indicated that sample extracts rarely require cleanup. New Jersey soils, on the other hand, almost always need to be cleaned up.

Tetrachlorodibenzodioxin (TCDD) is introduced into the instrument via a capillary GC column programmed at 20 °C/min. Under these conditions, the peak elutes in about 5 min. In the source, TCDD is ionized to give a parent ion of the same mass as the molecular weight of the neutral compound:

$$TCDD + NO^+ \longrightarrow TCDD^+ + NO$$

Table 4
Detection Limits and Maximum Measured Concentrations of Selected Compounds in Ambient Air

Compound	Concentration, ppb Detection Limit	Maximum STP	Maximum Industry B
Benzene	5	60	7
Toluene	2	30	80
Dichlorobenzene	0.3	12	3
Chloroform	4	150	ND
Trichloroethylene	30	ND	ND
Acetone	15	70	30
Methyl ethyl ketone	10	14	55
Methylthiazole	1	14	11
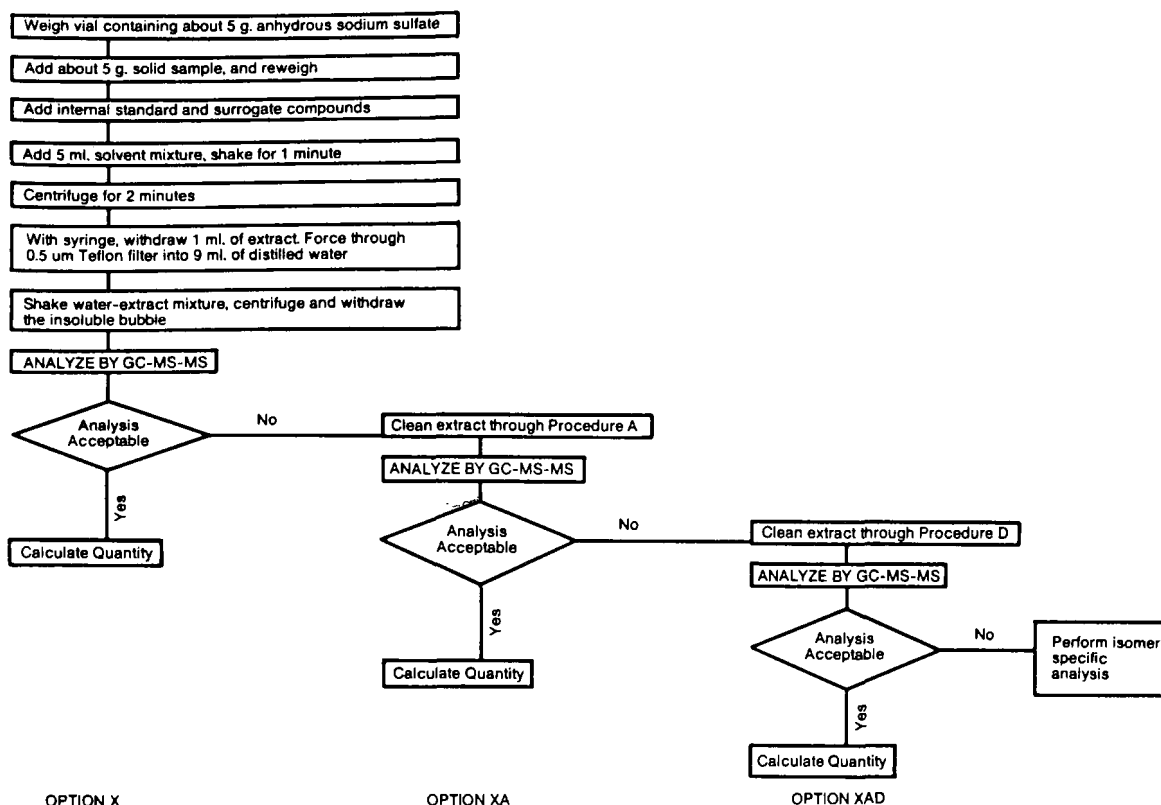
Figure 8
TCDD Sample Preparation and Analysis Scheme Using GC/MS/MS

Typical fragmentation of TCDD$^+$ is shown in Figure 9. The major ions formed during fragmentation are:

m/z	Identity
320	TCDD$^+$, parent ion
285	(TCDD − Cl)$^+$, neutral loss of chlorine from parent ion
257	(TCDD − COCl)$^+$, neutral loss of COCl group from parent ion
222	(TCDD − COCl$_2$)$^+$, neutral loss of COCl and Cl from parent ion
194	(TCDD − 2COCl)$^+$, neutral loss of two COCl groups from parent ion
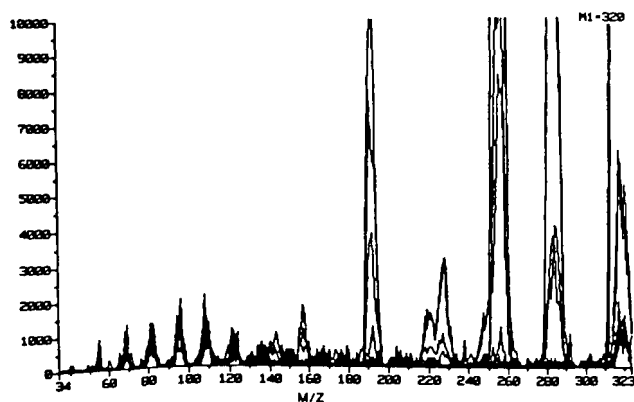
Figure 9
Fragmentation Pattern for TCDD
Parent M/Z = 320

Instrumental parameters are optimized so that the parent ion is minimized and the fragment ion of mass 257 is maximized. Under these conditions, native TCDD will also exhibit a fragment of mass 259 due to the natural distribution of chlorine isotopes. The surrogate, 37Cl$_4$ − TCDD, will appear at mass 263, and the internal standard, 13$_{C_{12}}$ − TCDD, will appear at mass 268. Hence, in the analysis, the instrument is set to monitor four parent-daughter ion pairs. These are shown below:

Component	Parent ion m/z	Daughter Ion m/z
Native TCDD	320	257
Surrogate, 37Cl$_4$ − TCDD	322	259
Internal standard	328	263
13$_{C_{12}}$ − TCDD	332	268

Because this capability of the dual selection of ions provides for the selectivity of the method, the extensive sample clean-up to remove interferents is not necessary.

The reproducibility of the system has been verified in an actual field application by analyzing a 10 ppb standard on a daily basis. The results are shown in Table 5. Another measure of the reproducibility of the technique was obtained by repetitive analyses of a well-homogenized soil. These results are shown in Table 6.

More recently, a rigorous statistical comparison of the technique to the conventional GC/MS method has been performed. In this study, five Missouri soils and one New Jersey soil were analyzed each in six replicates by each of the techniques. The results, although not fully evaluated yet, are shown in Table 7. In this study, each extract of the MS/MS method was analyzed with no cleanup, after the first cleanup step, and after both cleanup steps. If a particular run did not meet internal quality assurance

Table 5
Reproducibility of GC/MS/MS System Based on Repeated Analysis of A Standard 10 ppb Solution

File	Calculated TCDD, ppb	Percent. Deviation From Known (10 ppb)
August 1701	10.05	0.5
August 1801	10.26	2.6
August 1901	9.75	2.5
August 2301	11.42	14.2
August 2302	11.00	10.0
August 2401	10.72	7.2
August 2501	10.69	6.9

Table 6
Reproducibility of Method Based on Repeated Analyses of Well-Homogenized Soil

File	Calculated TCDD, ppb
August 1067	5.4
August 1069	6.3
August 1106	4.7
August 1110	6.3
August 1212	5.0
August 1219	4.0
August 1222	5.9
August 1615	4.9
August 1714	5.9
August 1810	5.2
August 1912	6.2
August 2217	5.7
August 2313	5.4
August 2508	6.1
Mean	5.5
Standard deviation	0.68

measures, its results are omitted from the table. The results clearly indicate that Missouri soils can be analyzed with confidence, with little or no cleanup. New Jersey soils do require cleanup.

This method offers a rapid technique for the analysis of dioxin in soil. Without cleanup, the entire procedure requires 15 to 20 min

Table 7
Comparison of MS/MS and GC/MS Methods for TCDD Analysis

Soil	WESTON's GC/MS/MS Results, ppb			EPA Region VII GC/MS Results, ppb
	X	XA	XAD	
Missouri 1	<0.13	<0.13	<0.13	<0.08
Missouri 2	1.72	1.74	1.76	2.01
Missouri 3	---	2.86	2.95	3.07
Missouri 4	6.39	6.37	6.53	6.98
Missouri 5	16.0	15.8	15.7	18.1
New Jersey	---	---	9.36	6.78

per sample. Even with both stages of cleanup, the sample preparation can be completed in 30 min per sample. Hence, by judicious staffing and planning, the technique can be employed as a rapid screening method, yielding approximately 25 sample analyses per 8-hr day.

CONCLUSIONS

The mobile MS/MS technology has proven itself in field applications in air analysis and in TCDD analysis. This powerful tool offers capabilities that previously have been impossible to achieve. Much of this work has been aimed at demonstrating the equivalency of the result to the conventional methodology but, heretofore, no conventional technique provides real-time or virtually real-time analysis for so many different situations and parameters. The application of the technology is still in its infancy, and its extension is limited only by the ingenuity of the operators.

SAFETY AND HEALTH INFORMATION FOR USE IN RESPONDING TO HAZARDOUS WASTE EMERGENCIES

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INTRODUCTION

The term "emergency" has been defined by the *American Heritage Dictionary* as a situation or occurrence of a serious nature, developing suddenly and unexpectedly and demanding immediate action. Certainly this term aptly describes those situations involving leaks, fires, explosions, etc., at chemical waste disposal sites. The ability of responsible parties to take the immediate action necessary for minimizing damage to life and property depends on their emergency-preparedness.

Facilitated by passage of CERCLA, Federal and some state governments have developed sophisticated emergency response units, superbly equipped and organized and staffed with trained professionals. However, regardless of how well-trained or knowledgeable emergency staff may be, it is virtually impossible to master the entire compendium of facts necessary to address the vast array of potential concerns posed by hazardous chemical emergencies. Therefore, the possession of information to support immediate life and property-saving decisions must be considered a vital component of "preparedness".

Emergency decisions may be needed in a variety of areas including firefighting methods, personal protective equipment and clothing, evacuation, containment of spills and runoff, inactivation of reactive substances, ultimate disposal strategies, etc. Definitive information in these areas, as well as adjunctive, substance-specific data such as those on chemical/physical properties, reactivity, flammability/explosivity, human toxicity, ecotoxicity and environmental fate of individual chemicals are essential. Further, each emergency may involve totally different sets of chemicals with their own set of attendant hazards. Therefore, information to support the types of decisions above must be available for a full range of chemical substances and compounds. Finally, the importance of the decisions and the less-than-ideal circumstances under which they must be made demand that information be reliable, concise and easily accessible.

In the remainder of this paper, the author describes some of the more important sources of information for use in responding to hazardous waste and spill emergencies. Sources are organized according to the physical format in which they are available, i.e., computerized database or hardcopy reference.

COMPUTERIZED DATABASES

Computerized databases usually can be categorized as either bibliographic or factual/numeric. Bibliographic databases contain references or abstracts of the literature which usually focus on a given subject area or theme. The National Library of Medicine's (NLM) Toxicity Information Online (TOXLINE) is a good ex-ample. TOXLINE contains some 1,500,000 citations, most with abstracts, covering pharmacological, biochemical, physiological and toxicological effects of drugs and other chemicals.

Factual/numeric databases contain data from a wide variety of sources which, through structured selection and formatting, yield profiles of given subjects, e.g., hazardous chemicals. Because the salient data have been organized for easy access, this type of database lends itself more to effective utilization in emergency situations than the bibliographic type. Major factual/numeric databases relevant to the information needs of emergency response personnel are described below.

CESARS

The Chemical Evaluation Search and Retrieval System (CESARS) contains information on over 180 chemicals; 185 data fields contain data on physical/chemical properties, uses, production volume, acute toxicity, chronic toxicity, carcinogenicity, mutagenicity, teratogenicity, bioaccumulative properties, metabolism, degradation products and associated hazards. Developed through a joint venture of the Michigan Department of Natural Resources and Region V, USEPA, this file contains fully referenced summarized information from a comprehensive review of the literature. Available through the USEPA's Chemical Information System (CIS), CESARS affords the user the ability to manipulate very detailed information for the purpose of data analyses.

HAZARDLINE

This database contains information on over 3,200 chemicals, with data on emergency response, safety, toxicity, signs and symptoms, first aid, regulations and special bulletins for news/current awareness. Developed by Occupational Health Services, this database is available directly via Tymnet (Tymshare, Inc.) and STSC networks. HAZARDLINE data is presented in a handbook format on a user-friendly, menu-driven system, i.e., the user interacts with the system at his own terminal to search for, manipulate and retrieve data specific to his needs.

OHMTADS)

The Oil and Hazardous Materials Technical Assistance Data System (OHMTADS) contains information on approximately 1200 substances; 126 fields contain data on physical/chemical properties, biological, toxicological, cleanup/disposal and commercial data. Maintained by the USEPA and available through CIS, this database emphasizes information useful in the assessment of hazards and response activities associated with the release of harmful substances into the aquatic environment.

RTECS

The Registry of Toxic Effects of Chemical Substances (RTECS) contains information for over 64,000 substances, with data on acute and chronic toxicity, primary skin and eye irritation, carcinogenicity, mutagenicity, teratogenicity, Federal regulations and status of major tests performed. Maintained by the National Institute for Occupational Safety and Health (NIOSH), this database is available via the NLM's Medical Literature and Retrieval System (MEDLARS) and through CIS.

TDB

The Toxicology Data Bank (TDB) contains information on over 4,000 substances, with data on toxicity, environmental fate and effects, safety and handling, physical/chemical properties and regulations. The TDB has undergone a recent expansion to include some 140 data elements organized into nine major categories of information. The expansion was directed toward the needs of hazardous substance emergency response activities. This comprehensive, peer-reviewed database is maintained by the NLM and is available via MEDLARS.

HARDCOPY REFERENCES

Hardcopy references represent relatively inexpensive, easy-to-use sources of information. In addition, their portability is highly desirable for use in the field. However, because of their physical form they are much more difficult to update than their computerized counterparts, resulting in long lag times in the addition of new data. Also, the static nature of hardcopy information does not allow for rapid collation of data within or among such sources. Major hardcopy references for use in hazardous waste emergency response are described below.

- *Catalog Handbook Of Fine Chemicals* 1984-1985
  Aldrich Chemical Company
  Published bi-annually by the Aldrich Chemical Co., this book contains information on some 14,000 substances, giving primarily substance identification and chemical/physical properties. Indexed by molecular formula and chemical name, this book is a high-quality source for boiling points, melting points and density data.

- *Chemical Hazard Response Information System* (CHRIS) Manual 2
  U.S. Department of Transportation, U.S. Coast Guard
  U.S. Government Printing Office, Washington, D.C., 1978.
  Developed by the U.S. Coast Guard, this manual contains information on approximately 800 substances, giving chemical/physical properties, safety and handling, toxicity, environmental fate/exposure potential, manufacturing/use and substance identification. Intended for use by USCG field personnel, this manual has become a popular source of information for hazardous waste emergency response.

- *Clinical Toxicology Of Commercial Products*-4th ed.
  Gosselin, R.E., et al.
  Williams and Wilkins Co., Baltimore, MD, 1976.
  This easy-to-use book contains information on 4,288 chemicals, with data on substance identification, safety and handling, toxicity, environmental fate/exposure potential and pharmacokinetics. Indexed by trade name, chemical uses and manufacturer's name, this book is a good source of information on formulations and antidote and emergency treatment.

- *Dangerous Chemicals Emergency First Aid Guide*
  Croner Publications Ltd., Surrey, England.
  This guide contains information on signs and symptoms, toxic hazard ratings and antidote and emergency treatment for 2000 chemicals.

- *Dangerous Properties Of Industrial Materials*-5th ed.
  Sax, I.N.
  Van Nostrand Reinhold Co., New York, NY, 1979.
  This book contains data on toxicity, environmental fate/exposure potential and exposure standards for 15,000 substances. It is indexed by chemical.

- *Emergency Handling Of Hazardous Materials In Surface Transportation*
  Bureau of Explosives, Association of American Railroads, Washington, D.C., 1981.
  This book contains substance identification and response information for 2,500 hazardous substances.

- *Environmental Monitoring Series: Hazardous Materials Spill Monitoring—Safety Handbook And Chemical Hazard Guide*
  USEPA, Washington, D.C., 1979.
  This book contains toxicity, first aid, and exposure protection information for 655 chemicals. It was intended for use by spill monitors, cleanup personnel and on-scene coordinators.

- *Farm Chemicals Handbook*
  Meister Publishing Co., Willoughby, OH, 1983.
  This annually updated book contains substance identification, manufacturing/use, toxicity, chemical/physical properties and safety and handling information for 6,500 chemical and trade-name substances. It is indexed by subject but is not referenced.

- *Fire Protection Guide On Hazardous Materials*-7th ed.,
  National Fire Protection Association, Boston, MA, 1978.
  This book contains 8,800 flash points, 3,550 mixture reactions, 1,300 fire hazard properties and 416 hazardous chemical reports covering some 10,000 substances. It is referenced but not indexed.

- *Guidelines For The Selection Of Chemical Protective Clothing,*
  American Conference of Governmental Industrial Hygienists, 1983.
  This book is a relatively unique compendium of information on the impermeability of various protective clothing materials to some 300 chemical substances. It is referenced and indexed by chemical and chemical class.

- *Hazardous Materials—1984 Emergency Response Guidebook*
  U.S. Department of Transportation, Washington, D.C., 1984.
  This book contains useful response data (some generic) for 1400 substances. Its coverage of recommended evacuation distances is notable.

- *Handbook of Chemistry And Physics*
  Weast, R.C., ed.
  CRC Press, Boca Raton, FL, 1979.
  This book is a major source of chemical/physical properties for numerous organic and inorganic chemicals. It also contains information on analytical methods, is referenced and is indexed by subject.

- *Handbook For Environmental Data On Organic Chemicals*
  Verschueren, K.
  Van Nostrand Reinhold Co., New York, NY, 1977.
  This book contains manufacturing/use, chemical/physical properties and toxicity data for approximately 2000 organic chemicals. It is referenced and indexed by chemical name.

- *Handbook Of Poisoning*-10th ed.
  Dreisbach, R.H.
  Lange Medical Publications, Los Altos, CA, 1983.
  This book, covering 1200 substances, emphasizes information on clinical findings, signs and symptoms and treatment. It is referenced and indexed by subject and chemical.

- *Handbook Of Reactive Chemical Hazards*-2nd ed.
  Bretherick, L.
  Butterworth, London, England, 1979.
  Covering over 3000 substances, this book emphasizes information on substance identification and hazardous reactions. It is referenced and indexed by chemical and subject.

- *Handbook of Toxic and Hazardous Chemicals*
  Sittig, M.
  Noyes Publications, Park Ridge, NJ, 1981.
  Covering some 600 substances, this book contains concise chemical property data and health and safety information useful to professionals who must make expeditious public health decisions.

- *Herbicide Handbook*-4th ed.
  Weed Science Society of America, Champaign, IL, 1979.

This book contains data on environmental fate and antidote and emergency treatment for exposure to 144 substances. It is referenced and indexed by chemical and product names.

•*Herbicides: Chemistry, Degradation, And Mode Of Action*-
2nd ed.
Kearny, P.C. and Kaufman, D.D., eds.
Marcel Dekker, Inc., New York, NY, 1975.

This book emphasizes information on environmental fate for more than 1000 herbicides. It is referenced and indexed by author, chemical and subject.

•*Material Safety Data Sheets*-General Electric Co.
Nielsen, J.M., ed.
General Electric Co., Schenectady, NY, 1980-83.

This compendium of material safety data sheets (MSDA) contains a full range of information on 523 chemicals and 275 tradename substances with about 100 new chemicals added per year. Each MSDS is referenced and the compendium is indexed by chemical.

•*Merck Index*-10th ed.
Windholz, M., *et al.* eds.
Merck and Co., Inc., Rahway, NY, 1983.

This book contains data on 10,000 chemicals and covering substance identification, manufacturing/use, safety and handling and toxicity. Its coverage of chemical/physical properties is notable. It is referenced and indexed by CAS name and number.

•*NIOSH/OSHA Occupational Health Guidelines For Chemical Hazards*
Mackison, F.W., *et al.* eds.
U.S. Government Printing Office, Washington, D.C., 1981.

This guideline series contains data on 398 chemicals covering substance identification, chemical/physical properties, toxicity and safety and handling. It is referenced but not indexed.

•*POISINDEX*
Rumack, B.H., ed.
Micromedex, Inc., Denver, CO.

Available only in microfiche, this source nevertheless contains extensive information on the treatment of approximately 575 toxic substances. It is updated quarterly.

DISCUSSION

Noteworthy advances have been, and are continuing to be, made in compiling, organizing and delivering hazardous waste and spill emergency response data. However, certain undeniable weaknesses still exist. In general, even the major sources focus primarily on the high production-volume chemicals, leaving extensive gaps in a responder's ability to deal with the lesser characterized substances which also find their way into disposal sites.

Further, information on mixtures, including popular trademark compounds, is grossly insufficient. Also, no single source contains the complete menu of necessary data. As a consequence, emergency response personnel often must rely on a number of sources, thus diminishing available response time. Chemical-specific data on reactivities, inactivation procedures, detailed cleanup/disposal methods and suitable (impermeable) material for protective clothing are all in need of further development. Lastly, because of logistical and economic difficulties, most sources are, at best, only infrequently updated.

The foregoing problems are not insurmountable. Continual advances in computerized delivery systems, research to fill data gaps and Federal support are all contributing to improvements. In addition, the Occupational Safety and Health's (OSHA) new Hazard Communication Standard (29 *CFR* 1910.1200) should establish a standardized, comprehensive base of chemical information. The standard covers all chemicals produced, imported or used within the United States' manufacturing sector and requires that employers provide labeling, material safety data sheets and employee training.

METHODOLOGY FOR SCREENING AND EVALUATION OF REMEDIAL TECHNOLOGIES

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INTRODUCTION

Sections 300.68(g), (h) and (i) of the National Contingency Plan (NCP) outline a three-level process for selection of the most appropriate remedial actions for a given site. First, a limited number of remedial action alternatives are developed based on site problems. Second, an initial screening of each alternative is made to eliminate those which are clearly inappropriate or infeasible. The third level of the process involves a detailed analysis of a limited number of alternatives which remain after the initial screening. One goal of the NCP is to ensure, to the extent practicable, that these remedial alternatives meet the need for protection of public health and welfare and the environment in the most cost-effective manner. Therefore, these broad criteria have been established for analysis during the remedial action selection process: acceptable engineering practices, costs; and public health, environmental and institutional effects.

In response to these requirements, a methodology was developed to provide guidance for the process of screening remedial technologies and developing remedial action alternatives. This methodology was prepared as a guidance document entitled "Methodology for Screening and Development of Remedial Responses" and is summarized in this paper.

An overview of the elements of the methodology, consisting of three steps, is shown in Figure 1. These important steps are:
•Identify general response actions
•Technology screening and alternatives development
•Technical evaluation of alternatives

The evaluation of remedial action technologies and alternatives is a highly complex process and in many instances relies on best engineering judgments. As a result, it is not the intention of this methodology to recreate in detail the thought process used in the screening and evaluation of remedial technologies and alternatives. Rather, the intent is to provide a system that can track and prompt the decision process involved in the technical screening of remedial action technologies, the development of remedial alternatives and the technical ranking of remedial alternatives.

To be more effective, the methodology should be integrated with the guidance forthcoming from the USEPA for conducting remedial investigations and feasibility studies under CERCLA.

IDENTIFY GENERAL RESPONSE ACTIONS

The first step is to identify existing site problems and the general response actions that may be applicable to remedying site problems. A general response action represents a group of remedial response technologies (i.e., air pollution controls, direct treatment) relevant to a specific site problem.

Definition of site problems relies on existing data collected in preliminary site studies for Superfund site ranking and evaluation efforts. The site problems are then matched to general response actions. A matrix for identifying applicable response actions based on site problems is given in Figure 2. There are 10 response action categories covering potential response elements. The process of matching site problems with response actions is an obvious first step and is critical to the overall remedial action selection process
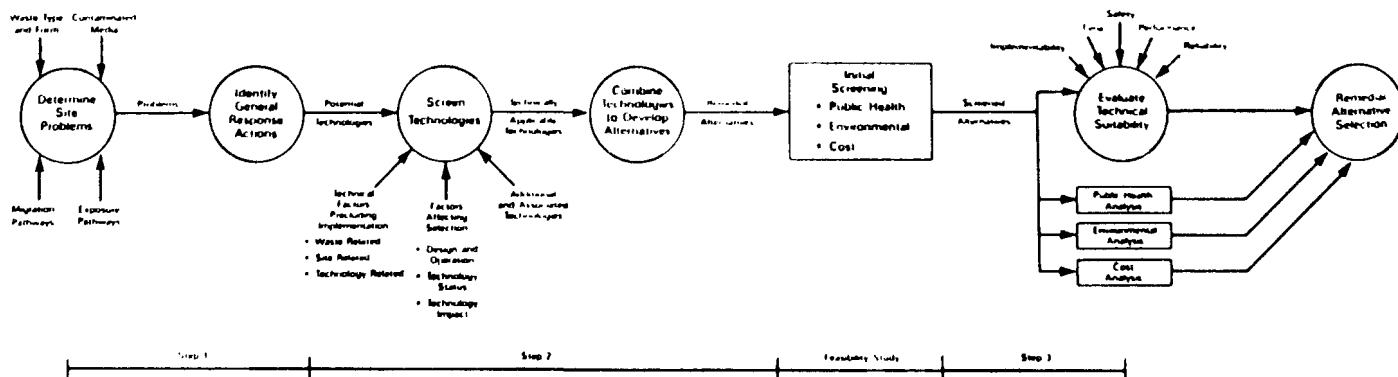
Figure 1
Technical Screening and Evaluation of Remedial Technologies and Alternatives

because it eliminates inapplicable responses, thereby limiting the universe of potential response actions and simplifying and focusing further screening and evaluation.

TECHNOLOGY SCREENING

The second step is to identify and screen potentially applicable technologies and then develop remedial alternatives. To do this, one first identifies feasible technologies to deal with specific problems. The methodology manual provides a comprehensive list of over 150 remedial technologies classified according to general response action categories. The general response actions thus determine "families" of potentially applicable technologies.

Figure 2
Matrix of General Response Actions for Specific Site Problems

In the screening process, one uses a series of screening tables to eliminate inappropriate technologies; this judgment is based solely on technical factors. A separate series of screening tables is provided for each of the ten general response action categories identified. Within each table, all potentially applicable technologies in a particular response category are listed and briefly described. These technologies are then further broken down into technology options.

An example screening table for a partial technology, listing of the general response action category, surface water controls, is shown in Table 1. One technology option is capping. Technology options within this category include clay cap, asphalt cap and synthetic liner.

Each screening table contains three additional columns that provide necessary information to screen technologies and subsequently develop alternatives. Under the second column, in Table 1, "Technical Factors Precluding Implementation," there is a list of limiting site, waste and technology characteristics which preclude implementation of the technologies. For example, the presence of very low permeability soils would be a site limitation that would ex-

clude the use of in situ treatment methods since it would be difficult to ensure complete mixing of treatment reagents with waste components. Also, the presence of a strongly acidic groundwater plume would be a waste limitation that would exclude the use of a downgradient, soil-bentonite slurry wall since the wall would be degraded by contact with acids. Further, technology limitations might include inherent operation, construction and maintenance problems. An example of a technology limitation would be the inability to dredge below 65 ft with a hydraulic dredge since that is the maximum reach for that type of equipment.

In addition to listing those factors precluding implementation, the screening tables also list "Critical Factors Affecting Selection." These factors do not necessarily preclude implementation under all circumstances, but they are listed in order to identify certain factors that need to be considered during screening and/or during the detailed evaluation of alternatives. Some of the factors listed under this column may affect performance or implementability to such an extent that a technology may be eliminated during technical screening. On the other hand, these factors may raise a "red flag" for concerns that need to be carefully considered during the additional screening of alternatives (cost, public health and environment). Examples of factors affecting selection are as follows:

- Design and operational considerations that significantly affect implementation and performance of technologies. For example, asphalt caps are subject to cracking. This limitation may make it difficult to maintain and monitor performance of an asphalt cap, particularly at a very large or remote site, and may be a basis for eliminating this technology option.
- Technology status is an item which requires close consideration during the screening process since the National Contingency Plan requires that technologies used for remedial actions be developed and demonstrated. However, in certain situations, technologies under development may be considered for application.
- The cost and impacts of associated technologies may reduce the feasibility of a particular technology. For example, the leaching of metals from a fly ash cap may preclude the implementation of this technique where the impacts would be unacceptable. Also, the requirements for specialized equipment to implement certain solidification/stabilization technologies may make these technologies cost prohibitive or unavailable under many circumstances. These are factors which will need to be considered further in the cost and impacts screening steps.

The final column in the screening table is designated "Additional Technologies" and includes a listing of both associated and secondary technologies. An associated technology is a technology that may be used together with the technology being screened to improve its performance. For example, a cap and a pumping system or subsurface drainage system are frequently used together with a circumferential slurry wall to minimize infiltration and prevent the bathtub effect or overtopping of a cap. A secondary technology is one that would be required to handle a secondary contamination problem that occurs as a direct result of implementing the technology being screened. For example, implementation of a groundwater pumping system generates an aqueous waste stream which generally requires treatment. Therefore, aqueous waste treatment would be considered a secondary technology. Combining associated and secondary technologies with the primary technology for resolving a site problem is actually the first step in building alternatives.

Technologies that have passed the technology screening process can then be combined to form overall alternatives that address all site problems identified. As mentioned previously, the screening tables provide a useful starting point in formulating alternatives from primary, secondary and associated technologies. This may be the only step required when a site has only one problem. More often, multiple site problems exist, so diverse, compatible technologies must be combined to address all site problems. In either case, a workable number of remedial alternatives must be developed based on feasible technologies that appear to adequately address all site problems.

Table 1
Example Screening Table for Surface Water Controls (Excerpt)

Technology	Technical Factors Precluding Implementation	Factors Affecting Selection	Additional Technologies
100. Capping Purpose: To control surface and prevent water infiltration	1. Not applicable to areas with very steep slopes (25%)	1. All capping materials are subject to degradation through ground subsidence 2. Lagoons must be filled and/or regraded prior to capping 3. Require regular inspection for burrowing animals and growth of deep-rooted plants	**Associated** 1. Grading (300) to control run-on and run-off 2. Revegetation (400) to prevent erosion 3. Gas collection systems (1000) to reduce build-up of hazardous or toxic vapors 4. Subsurface drains (800) to control leachate and prevent overtopping of cap **Secondary** 1. Gaseous treatment (1600) of collected gases 2. Aqueous waste treatment (1700) of collected leachate
101. Clay	1. Not favorable in arid climates 2. Not suitable for direct contact with organic or inorganic acids and bases		**Associated** 1. Covering with another soil layer prior to revegetation to maintain moisture in cap and prevent deterioration due to penetration by vegetation
102. Asphalt	1. Not favorable in areas where exposure to heat is excessive, such as arid climates 2. Not suitable for direct contact with high-concentration organics	1. Cracking (repairable) 2. Chemical and photodegradation 3. Contact with metals and soluble organics may be a problem	**Associated** 1. Polypropylene fabric underliners (103)
103. Synthetic liners	1. Not favorable in areas where exposure to heat is excessive 2. Not suitable when in contact with high concentrations of incompatible organics	1. May require extensive subgrade preparation 2. May require special cover 3. Subject to tearing and degradation through sunlight and exposure	**Associated** 1. Covering with another soil layer to protect from degradation through exposure

Given that a large number of technologies may pass the technology screening process and that a site may have a number of primary and secondary contamination problems, the number of applicable technologies and feasible alternatives could be very large. Then, best engineering judgment must be used to limit the number of alternatives considered for detailed evaluation. The methodology manual describes several general approaches for limiting the number of alternatives without affecting the credibility of the feasibility study. These methods involve various techniques to combine the permutations that may exist between and among technologies.

Once the remedial technologies have been screened and developed into remedial alternatives, these alternatives undergo an initial screening based on cost, health and environmental criteria. This screening is conducted under the feasibility study and serves to limit the number of remedial alternatives undergoing detailed analysis by eliminating alternatives that do not sufficiently address cleanup requirements. The alternatives remaining after this screening undergo the final, detailed evaluations.

TECHNICAL EVALUATION OF ALTERNATIVES

The third and final step is to determine the technical suitability of each alternative for dealing with the site-specific problems. Each alternative from the initial screening process is evaluated and then rated relative to the other alternatives with respect to performance, reliability, implementability, time and safety. As shown below, two measures have been designated for determining each of these five criteria:

•Performance
-Effectiveness
-Useful life
•Reliability
-Operation and maintenance requirements
-Demonstrated and expected reliability
•Implementability
-Site conditions affecting constructability
-External factors affecting implementation

•Time
-Time to implement
-Time to achieve beneficial results
•Safety
-Safety and health of workers
-Safety and health of nearby communities

Each of these measures is described in the guidance document, and a list of questions intended to assist in the evaluation of each alternative is provided. For example, questions that can be used to evaluate the effectiveness of a given alternative include:

•How effective is the technology/alternative in meeting site objectives (e.g., volume of contaminated material removed or contained; level of treatment achievable; volume of water diverted or collected)?
•Are there any site or waste characteristics which could potentially impede effectiveness?
•Is there any particular technology within the alternative which is limiting in terms of effectiveness?

The technical evaluation should include a written response for each of these questions, where applicable, to support the analysis process.

Once a written response has been prepared for each of the preceding questions, the technical ranking of alternatives can be performed using Figure 3. The alternatives can be ranked in order of their relative desirability with respect to each criterion. Alternatively, each remedial alternative and technology can be rated with respect to the absolute degree to which the alternative or technology effectively fulfills each criterion. If the relative evaluation method is chosen, the highest number is generally the number of alternatives under consideration. If the absolute evaluation method is chosen, the numerical values are generally ranges (such as 1 to 10; 1 to 5; or $-1, 0, +1$) with the lowest number representing a "base-line" alternative. Whichever is chosen, there should be a consistent numerical ranking with the highest number indicating the most desirable alternative or technology under each criterion.

One possible exception to the above scoring is the criterion for time. If so desired, the numerical value for time could be the

Alternatives	Performance		Reliability		Implementability		Time		Safety	
	Effectiveness	Useful Life	O&M Requirements	Demonstrated and Expected Reliability	Site Conditions	External Factors	To Implementation	To See Beneficial Results	Worker Health and Safety	Neighboring Communities

Figure 3
Technical Feasibility Ranking Summary

ACKNOWLEDGEMENTS

number of months or years relevant to each technology or alternative. The overall time could be the sum of the time required for implementation and achieving beneficial results. Note that the time to achieve beneficial results should not include implementation time.

To further support the ranking of alternatives, Figure 4, "Technical Evaluation Summary Sheet," is used to briefly summarize the major strengths and weaknesses of each alternative in terms of the evaluation criteria. This summary provides the public with a means of understanding the rationale used in ranking alternatives.

Alternative Name:

Alternative Description:

Performance
Effectiveness:
Useful Life:

Reliability
Operation and Maintenance Requirements:
Demonstrated and Expected Reliability:

Implementability
Site Conditions Affecting Constructability:
External Factors Affecting Implementation:

Time
Time to Implement:
Time to See Beneficial Results:

Safety
Safety and Health of Workers:
Safety and Health of Nearby Communities:

Figure 4
Technical Evaluation Summary Sheet

Concurrent with the technology evaluation are the analyses of the alternatives regarding cost, public health and environment. These four analyses will be combined in the feasibility study to develop the information to select the cost-effective remedial alternative.

CONCLUSIONS

The methodology presented in the procedures manual, "Methodology for Screening and Evaluation of Remedial Responses," is a three-step analysis method to be used in remedial investigations and feasibility studies conducted in the Superfund program. The methodology is a system for documenting the identification, screening, elimination and selection of remedial technologies and remedial alternatives. This method aids in the decision-making process by providing a formal, analytical framework that can be recreated for an individual site and provide consistency in approaching different sites. Finally, the selection methodology serves to generally structure a process that, in the past, has been more intuitive or conceptual in nature.

A SUPERFUND SITE ATMOSPHERIC STUDY: APPLICATION TO REMEDIAL RESPONSE DECISION-MAKING

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INTRODUCTION

Uncontrolled hazardous waste disposal sites vary considerably in the type, size, nature and amount of hazardous substances contained and in the nature and severity of hazards presented. They include landfills containing loose or containerized wastes and open dumps of barrels and drums. The hazardous substances may include organic solvents, waste oils, pesticides, heavy metals, inorganic acids, alkalis, salts, explosives, flammables, radioactives, carcinogens and infectious materials.

DESCRIPTION OF PROGRAM

The Lackawanna Refuse Site is located west of Keyser Avenue, Old Forge, Lackawanna County, Pennsylvania (Fig. 1). The site lies on the border between the Borough of Old Forge and Ransom Township.

This 258-acre Superfund site is located in a hilly area previously deep-mined and strip-mined for coal. The site area is hilly and forested except for an open area near the center of the site where the main disposal activity occurred. Open strip cuts were used for municipal and commercial waste disposal; industrial and hazardous wastes were also dumped in the same location. In addition, liquid wastes were allegedly dumped along the access road and in a strip cut along the access road known as the borehole pit.

The site is inactive. Surrounding land use includes former strip mining for coal, rural and agricultural activities and some residential use. Hunting occurs in areas around the site. The site is bordered by a few houses to the east and a trailer park to the southeast. The Austin Heights section of Old Forge Borough is northeast of the site. The area west of the site is hilly and forested. There is a population of approximately 9,500 within a 1-mile radius of the site, residing in the Borough of Old Forge.

As a result of the USEPA decision to pursue remedial action at the Lackawanna Refuse Site, a thorough remedial investigation was conducted. The purpose of the investigation was to assess the threat to public health, welfare and the environment posed by the site and to identify potential options to remedy the problem. As part of the remedial investigation, a feasibility study is currently being conducted; this study involves a detailed evaluation of feasible alternatives using economic, environmental and engineering factors.

Contamination Potential

A consideration in the feasibility study is the various dispersal pathways by which hazardous waste could potentially affect the surrounding area. Most common pathways are through the soil, groundwater, surface water, direct contact and the atmosphere. The Lackawanna Refuse Site is unique because the atmospheric pathway, in conjunction with the surrounding complex terrain, presented a potentially signficant threat to the nearby surrounding population when remedial action alternatives were considered.

In addition, an assessment of the air pathway became important for the preparation of emergency preparedness procedures for use at the site during planned exploratory excavations. Development of these procedures was necessary in the event of an accidental release of toxic substances to the atmosphere (e.g., breaking of a barrel of a liquid toxic chemical and subsequent volatilization of the substance).

Possible Air Pollution

Therefore, to assess the potential impact along the air pathway, an atmospheric field study was performed at the site. The objective of the field study was to characterize atmospheric transport and diffusion conditions in the near-vicinity of the site associated with potential ground-level releases of pollutants.

Local wind patterns may be complex at Lackawanna due to the influence of terrain features in and near the site. Thus, standard methodologies for evaluating atmospheric transport and dispersion may not be applicable. The objective of this field study is to characterize atmospheric transport and diffusion conditions in the near-vicinity of the site associated with potential ground-level releases. Specifically, the goal was to characterize airflow and dispersion during those meteorological conditions that have the greatest potential for impact on nearby neighborhoods. Those meteorological conditions can be classified into three categories:
- Regional flows from the southwest quadrant (the prevailing wind conditions at the site)
- Regional flows from the northwest quadrant (a secondary flow condition)
- Local flows from the west quadrant (generally associated with drainage downslope flows during periods of low regional wind speeds)

Regional winds from the southwest occur during all months of the year and are the predominant wind flow direction for every month except March. Regional northwest winds are common during the late fall, winter and early spring months and are the prevailing wind direction during the month of March. Drainage flow conditions, when they do occur, can be expected to occur predominantly at night and are most prevalent during the spring and fall and, to some degree, during the summer. The frequency is lower in the winter months. Daytime drainage flow conditions are
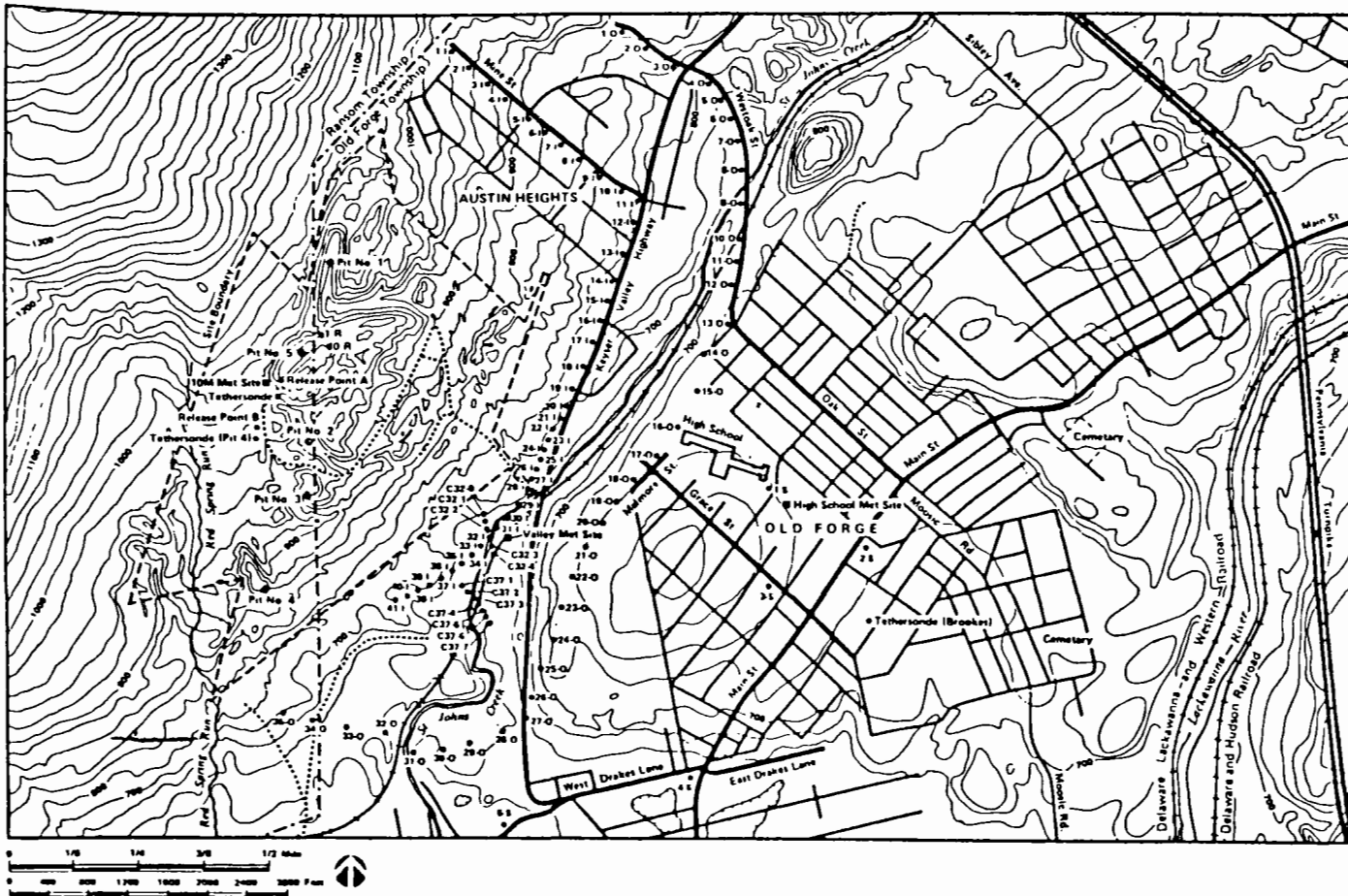
Figure 1
Lackawanna Site Area

rare, although possible, during the winter months if a snow cover is present, or near sunrise or sunset during any season.

The Dec. 6 through 20, 1983, atmospheric field program at the Lackawanna site consisted of three components:
•Meteorological monitoring
•Smoke releases
•Tracer releases

The technical approach for the tracer program involved release of sulfur hexafluoride (SF_6) as a tracer gas at a known release rate. A network of SF_6 samplers was deployed at locations downwind of the release. Concentrations measured at these sampling locations can be related to the source in order to determine relative dilution. These values can also be evaluated with wind and stability measurements to characterize atmospheric transport and dispersion conditions. Smoke releases were also used to visually observe the plume and provide qualitative transport information. Results from this field study provide a basis for estimating potential concentrations at locations in the site vicinity in the event of an accidental release.

Another paper is planned to address the technical aspects of the tracer study.

CONCLUSIONS

An atmospheric study has been completed for the Lackawanna Refuse Site. The analyses indicate that off-site meteorological data are not representative of the Lackawanna area atmospheric conditions due to the complex terrain at the site. Results from the study, however, provide a basis for characterizing atmospheric dispersion and transport in the site area. This study has facilitated the use of standard dispersion models with appropriately modified input and output data. The atmospheric study and subsequent modeling results have been applied to remedial action decision-making. This process included evaluation of air-pathway impacts associated with alternative site cleanup options. Another application has been for emergency preparedness associated with investigative excavations.

THE EFFECT OF WIND SPEED ON THE EMISSION RATES OF VOLATILE CHEMICALS FROM OPEN HAZARDOUS WASTE DUMP SITES

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INTRODUCTION

The increased recognition of widespread mismanaged hazardous waste disposal sites in the United States has caused environmental and public health officials to seek ways to identify ambient chemical exposures and evaluate their public health importance. In the past, the environmental health impact from these sites focused primarily on the contamination of local water supply aquifers. Recently, however, attention has been directed toward hazardous air emissions from uncontrolled hazardous waste sites.[1,2] The slow emission rates characteristic of this type of environmental contamination may produce long term chemical exposures which may, in turn, affect the health of neighboring communities.

Theoretical mathematical models have been developed to predict such emissions.[3,4] One such model[3] attempts to describe the surface evaporation of chemicals from saturated soil. Evaporation and diffusion under these conditions is a strong function of wind speed and temperature.

In this paper, the authors present the results of laboratory experiments conducted to evaluate the effect of wind speed on the chemical emission rates from different soil types. With proper consideration of wind speed, this model may be used in assessing the air emissions and, therefore, the public health impact of open chemical dumps or land-based spills.

BACKGROUND

In 1855, Adolph Fick[4] introduced a theory which stated that the diffusion of chemicals within various medias was similar to heat and electrical conduction:

$$J_z = -cD \ \frac{dx}{dz} \qquad (1)$$

Where: J_z = Flux Rate per Area (cm^2)
  c = Molar Density of the Fluid (g)
  D = Diffusion constant (cm^2/sec)
  z = Distance (cm)
  x = Mole Fraction of Chemical in Fluid or Soil (g)

A critical element of this equation is the diffusion constant, D. Several researchers have developed methods for calculating diffusivities from chemical data[5]. The method used here is Gilliland's *et al.'s* modification and is described by Shen.[3,6]

$$D = \frac{0.001T^{1.75}\sqrt{\frac{1}{M_1} + \frac{1}{M_2}}}{P\left[(\Sigma V_1)^{1/3} + (\Sigma V_2)^{1/3}\right]^2} \qquad (2)$$

Where: T = Temperature (degrees K)
  M1, M2 = Molecular weights of components 1 and 2 (g/mole)
  V1, V2 = Atomic Diffusion Volumes of components 1 and 2 (cm^3/mole)
  P = Chemical Vapor Pressure (mm Hg)

Since diffusivity is a strong function of temperature, emission and evaporation rates will vary considerably under varying environmental conditions. Shen[3] lists a number of the chemical diffusivities for many environmental contaminants at different temperatures. These are useful when calculating theoretical air emissions from hazardous waste sites.

Ziegler[7] modified Fick's Law for application to gaseous emissions from surface chemical spills in the form of open pools of liquid. Arnold[8] included a wind speed component to the equation which Shen[3] modified to consider land based spills. The form of the equation used in this paper is:

$$\text{Emission Rate} = 2 \text{ cw} \ \sqrt{\frac{D L V}{\pi F}} \ x \ \frac{m}{M} \qquad (3)$$
(cm^3/sec)

Where: c = Chemical Vapor Pressure (atm)
  w = Width of Land Spill or Landfill (cm)
  D = Diffusivity (cm^2/sec)
  L = Length of Land Spill of Landfill (cm)
  V = Wind Speed (cm/sec)
  F = Vapor Pressure Correction Factor
  m = Weight of Chemical in Soil (g)
  M = Weight of Chemical and Soil (g)

The above equation predicts the quantity of chemical expected to evaporate under given wind speed and temperature conditions. For determining the correction factor (F) see Figure 1. The Equation below can be used to convert the emission rate into mass units:

$$\text{Emission Rate} = \text{Emission Rate} \ x \ \frac{MW}{MV} \qquad (4)$$
(g/sec) (cm^3/sec)

Where: MW = Molecular Weight (g/mole)
  MV = Molecular Volume (cm^3/mole)

If the wind speed variable (V) of Equation 3 is isolated and expressed in exponential form, it can be seen that emission rate has been related to the wind speed to the 0.5 power:

$$\text{Emission Rate} = 2cw\frac{m}{M} \sqrt{\frac{DL}{\pi F}} * \frac{x}{V} \qquad (5)$$

or

$$\text{Emission Rate} = K * V^X$$

If the chemical and soil terms are defined as the constant K and Equation 5 is rearranged, then exponential wind speed term X can be expressed as:

$$X = \frac{\ln(E) - \ln(K)}{\ln(V)} \qquad (6)$$

Where: X = Exponential Wind Speed Constant
E = Emission Rate (cm^3/sec)
K = 1 Chemical and Soil Constant
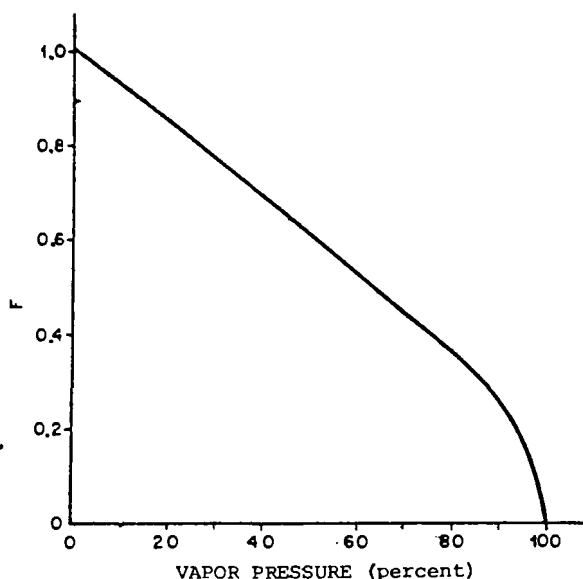
Figure 1
To Find Correction Factor F

Date Source: Reference 8

By experimentally determining the actual value of the wind speed exponent, Equation 3 becomes more valuable in predicting the chemical emission rates as wind speed varies. However, the rates predicted using Equation 3 are only applicable to the surface evaporation of chemicals from soils. Once the top layer of chemically contaminated soil evaporates, other equations may be used to predict sub-surface emission.[4,9]

METHODS AND MATERIALS

In order to calculate the wind speed function, experiments were set up to collect the necessary data. The experiments involved determining the actual emission rates for three commonly used organic solvents under varying conditions. The chemicals, benzene, carbon tetrachloride and trichloroethylene, are commonly used solvents and have been prevalent contaminants in hazardous waste sites. Three different soils were evaluated under three different wind conditions. Each experiment was done in triplicate to assure accuracy and reproducibility. The variables were:

Soils	-Clay, Sand and Organic Topsoil
Wind Speed	-0.5, 2.5 and 5.0 miles/hr (0.8, 2.4 and 8.0 km/hr)
Chemicals	-Benzene, Carbon Tetrachloride and Trichloroethylene

Some chemical properties of the test compounds are shown in Table 1.

Table 1
Chemical Properties of Test Compounds[6]

Properties	Benzene	Carbon Tetra-chloride	Trichloro-ethylene
Formula	C_6H_{66}	CCl_4	$CHCl:CCl_2$
Mol. Weight	78.11	153.82	131.39
Boiling Pt. °C	80.0	76.9	87.1
Vapor Pressure			
mm Hg at 20°C	74.5	87.4	60.0
Density at 25°C (g/ml)	0.87	1.58	1.46
Diffusivity at 25°C			
(cm^2/sec)	0.088	0.082	0.084

The experiments involved saturating a known amount of soil in a shallow stainless steel evaporation pan and measuring the loss of chemical using gravimetric procedures. The soils were pre-dried so that any change of weight would be attributed to vaporization and vapor diffusion leaving the tray and soil. The loss was measured at precise 15 min. intervals and this, together with other chemical, soil and wind speed information, was used to calculate the wind speed exponent.
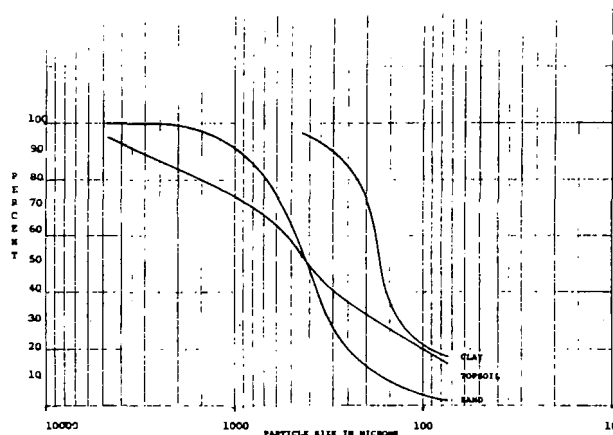
Figure 2
Plot of Particle Size Versus Percent Retained

The three soils tested varied significantly with respect to density, porosity and particle size distribution (Table 2). The sandy soil was the least porous and the organic topsoil the most. The topsoil was also clearly more organic than the other two and had a wider range of particle distribution (Figure 2).

Table 2
Physical Characteristics of Test Soils

Soil Type	Porosity (%)	Density (g/ml)
Clay	48	1.34
Sand	32	1.59
Topsoil	51	0.96

Each experiment was repeated under three varying wind conditions. These were simulated using various methods and proved consistent and accurate throughout the experiment. Verification of wind speed was done using a calibrated Alnor Velometer.

Measurements were made repeatedly at the air-soil interface during each experiment with little variation observed. Evaporation rates were determined by saturating a known volume of pre-weighed moisture-free soil (750 ml) and measuring the weight of
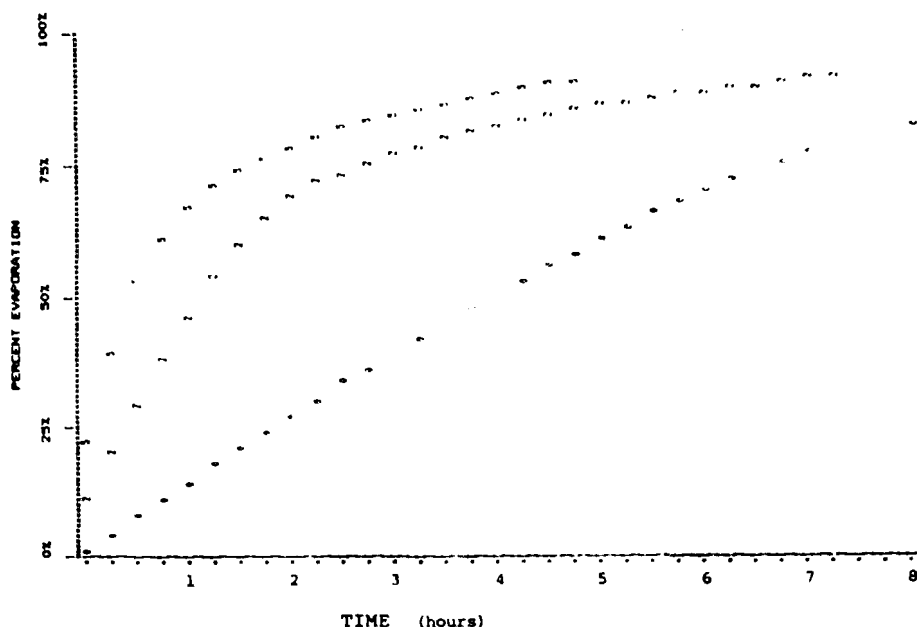
Figure 3
Evaporation of Benzene from Clay at 0.5, 2.5 and 5.0 mph Wind Speed

change at specific intervals. The evaporation trays used were 1.45 cm x 1.95 cm x 0.31 cm with a surface area of 282 cm^3. Evaporation rates vary with temperature, therefore measurements were taken at the beginning and at various intervals throughout each experimental run.

RESULTS

The initial, or first 15 min, emission rates (g/min) for each experiment are listed in Table 3. Figure 3 contains a plot of the emission rate for benzene in clay at all three wind speeds. The shapes of the emission curves for the other combinations of soil and chemical are similar to Figure 3.

Table 3
Observed Surface Emission Rates of Benzene, Carbon Tetrachloride and Trichloroethylene in Clay, Sand and Topsoil During the First 15 Minute Evaporation Interval in Grams per Minute

Chemical	Wind Speed (mph)	Wind Speed (km/hr)	Emission Rates Clay	Emission Rates Sand	Emission Rates Topsoil
Benzene	0.5	0.8	0.867	0.933	0.667
	2.5	2.4	2.200	2.200	2.333
	5.0	8.0	4.533	3.667	4.600
Carbon Tetrachloride	0.5	0.8	1.467	1.667	1.400
	2.5	2.4	4.200	4.000	4.800
	5.0	8.0	9.533	7.333	11.133
Trichloro-ethylene	0.5	0.8	0.933	0.800	0.800
	2.5	2.4	2.733	2.600	3.133
	5.0	8.0	6.000	5.333	7.933

The observed emission rates of Table 3 (after being converted to cm^3/sec) were used in Equation 6 for the calculation of the exponential wind speed function. In calculating the wind speed constant of Equation 6, the diffusivity, vapor pressure and emission rate volume (cm^3/sec) were all adjusted for temperature.

Table 4
Calculated Wind Speed Constant of Equation 6

Chemical	Clay Wind 0.5	Clay Speed 2.5	Clay mph 5.0	Sand Wind 0.5	Sand Speed 2.5	Sand mph 5.0	Topsoil Wind 0.5	Topsoil Speed 2.5	Topsoil mph 5.0
Benzene	0.71	0.66	0.71	0.86	0.73	0.74	0.50	0.60	0.65
CCl^4	0.63	0.63	0.71	0.79	0.71	0.72	0.49	0.59	0.67
Trichlr	0.65	0.65	0.72	0.73	0.73	0.77	0.48	0.61	0.71

The overall mean for all combinations of soil, chemical and wind speed was 0.67. No significant difference in this constant was observed between the chemicals tested. However, a significant difference (p $<$0.002) was observed between soil types. The difference is especially pronounced in the topsoil sample. This implies that in using equation 3, the appropriate wind speed constant should be selected depending on the soil type (Table 5).

Table 5
Wind Speed Constants

Soil Type	Wind Speed Constant
Clay	0.67
Sand	0.75
Topsoil	0.60

As expected, the actual wind speed did not correlate well with the wind speed constant for the clay and sandy soils. However, topsoil did show a strong correlation (R = 0.97). The reason for this is probably due to the organic content of the topsoil sample. The soil tested was significantly more organic than either the clay or sand. This organic fraction could have pronounced effects on chemical retention through either adsorption or increased porosity.

Even though Figure 2 shows that the clay soil contained the greatest number of small particles, topsoil was found to have a porosity of 51%, the highest of all samples. The reason for this is the difference between open and trapped pores found in soils. The topsoil contained significant amounts of organic detritus, therefore

much space existed within particles (i.e., porous wood chips). These trapped air spaces would result in less chemical evaporation and vapor pore diffusion and would, therefore, explain the reduced emission rates observed in all topsoil experiments.

Once the chemical begins to evaporate from the pores of the soil, the actual surface area exposed to the travelling air decreases significantly. Wind speed is not as critical in determining the emission rates of below surface contamination. Therefore, Equation 3 should not be used after the material has visibly evaporated from the soil surface. The time for this step to occur is strongly dependent on wind speed, but for the chemicals and soils tested here, Equation 3 was reasonably accurate for up to 30 min after a spill. Since the wind speed constant determined in this experiment linearly decreases with time, Equation 3 could be modified to account for this variation. Other equations are available for predicting subsurface emission rates.[4,9] These are also based on Fick's Law and consist of all the variables of Equation 3 as well as soil porosity, tortuosity and the depth of contamination.

If the equations are to be used for determining the organic vapor emission rate from open hazardous waste landfills, some modifications are necessary. First, the experiments presented here are using moisture-free soil. In reality, all soils contain some moisture which may inhibit or accelerate evaporation and pore diffusion. The effect of moisture on the emission rates can be quite varied depending on various oil and chemical characteristics.

Second, the soil column tested was extremely homogeneous. In normal situations, the quality of the soil will vary substantially with depth.

Third, wind speed is rarely consistent, therefore average wind speeds must be used as well as wind direction. Finally, surface temperature may significantly vary from air temperature at times of high solar radiation. Because vapor pressure and diffusivity are both strongly affected by temperature, it is important to take temperature readings at the air/soil interface and not rely on ambient temperature readings.

In representing any environmental phenomena using a mathematical model, there is a significant chance that the model either overestimates or underestimates the true situation. By introducing new variables in the mathematical relationship and adjusting others, reasonable estimates can be made. Previous research has shown Equation 3 to be within 50% to 150% of the actual emission rates for all soil and chemical combinations.[9] By correcting the relationship of wind speed using the data presented here (Table 5), the estimates are much closer to the true emission rates observed.

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AIR MONITORING AT A MAJOR HAZARDOUS WASTE CLEANUP SITE: OBJECTIVES/STRATEGY/RESULTS

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INTRODUCTION

On December 3, 1982, the U.S. Army Corps of Engineers issued an invitation for bids for waste removal at the Chem-Dyne hazardous waste site in Hamilton, Ohio. The principal components of the project included:

- Construct decontamination and drum staging areas
- Confirm or test contents of 30 tanks and 8600 drums
- Dispose of all waste in approved sites by use of appropriate haulers

The Chem-Dyne site covered approximately 10 acres, and most of it was enclosed by a fence installed along the perimeter. The site is bounded on the north by a canal, on the west by a factory building, on the east by an open field and on the south by a residential area (Figs. 1 and 2).

While in operation, the Chem-Dyne facility was used for the storage and reprocessing of wastes. At the state of the cleanup activity, the site contained 31 above-ground tanks, two below-grade open-top tanks, approximately 8,600 drums, two tanker-trailers, eight semitrailers, one flatbed truck and one flatbed railroad car.

AIR MONITORING OBJECTIVES

Among the materials known to be present on the site were large quantities of organic solvent mixtures. These volatile organic compounds had the potential for producing an adverse impact on public health. The prime cleanup contractor, O.H. Materials, awarded PEI a contract to conduct perimeter air monitoring at the site and to perform subsequent (within 48 hr) gas chromatography/mass spectrometry (GC/MS) analysis of the samples collected. The objectives of the overall project were to minimize the release of any organic vapors and to perform off-site monitoring to measure concentrations of the various types of vapors that may have been released from the site as a result of the cleanup work and the general contaminated nature of the site.

Figure 1
Chem-Dyne Site Location Map
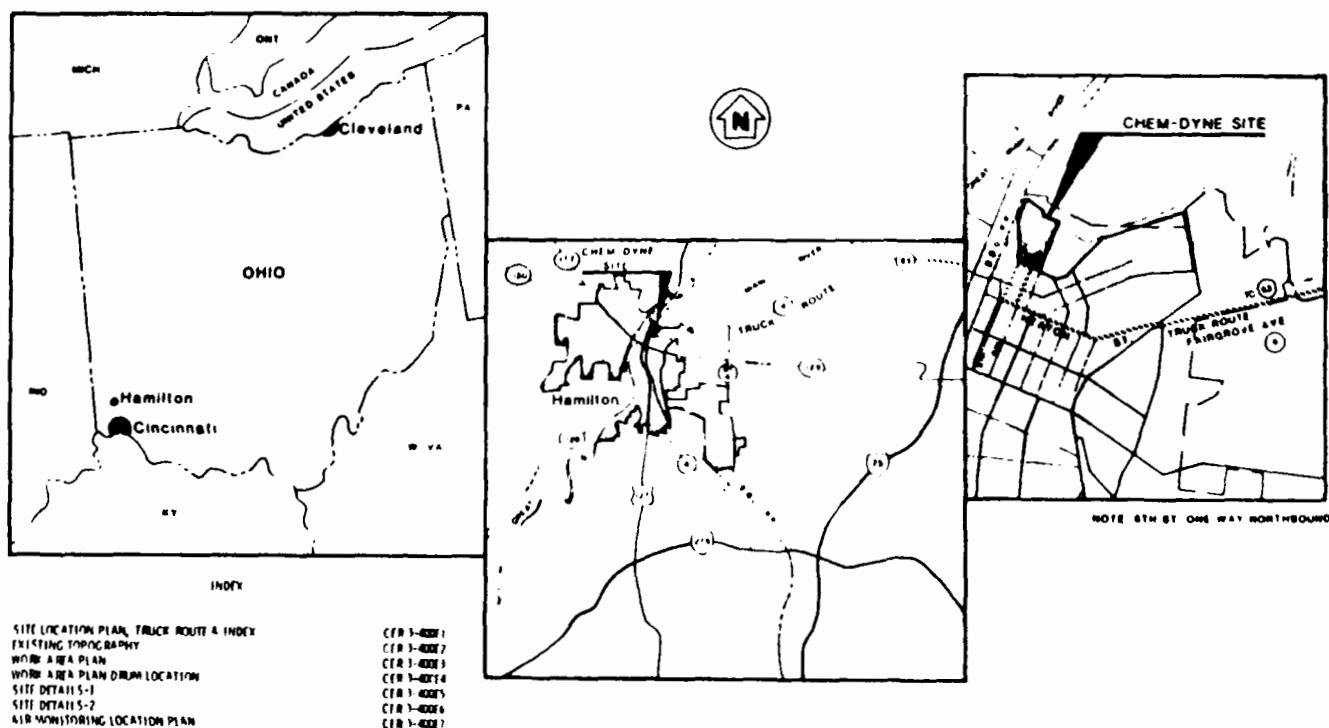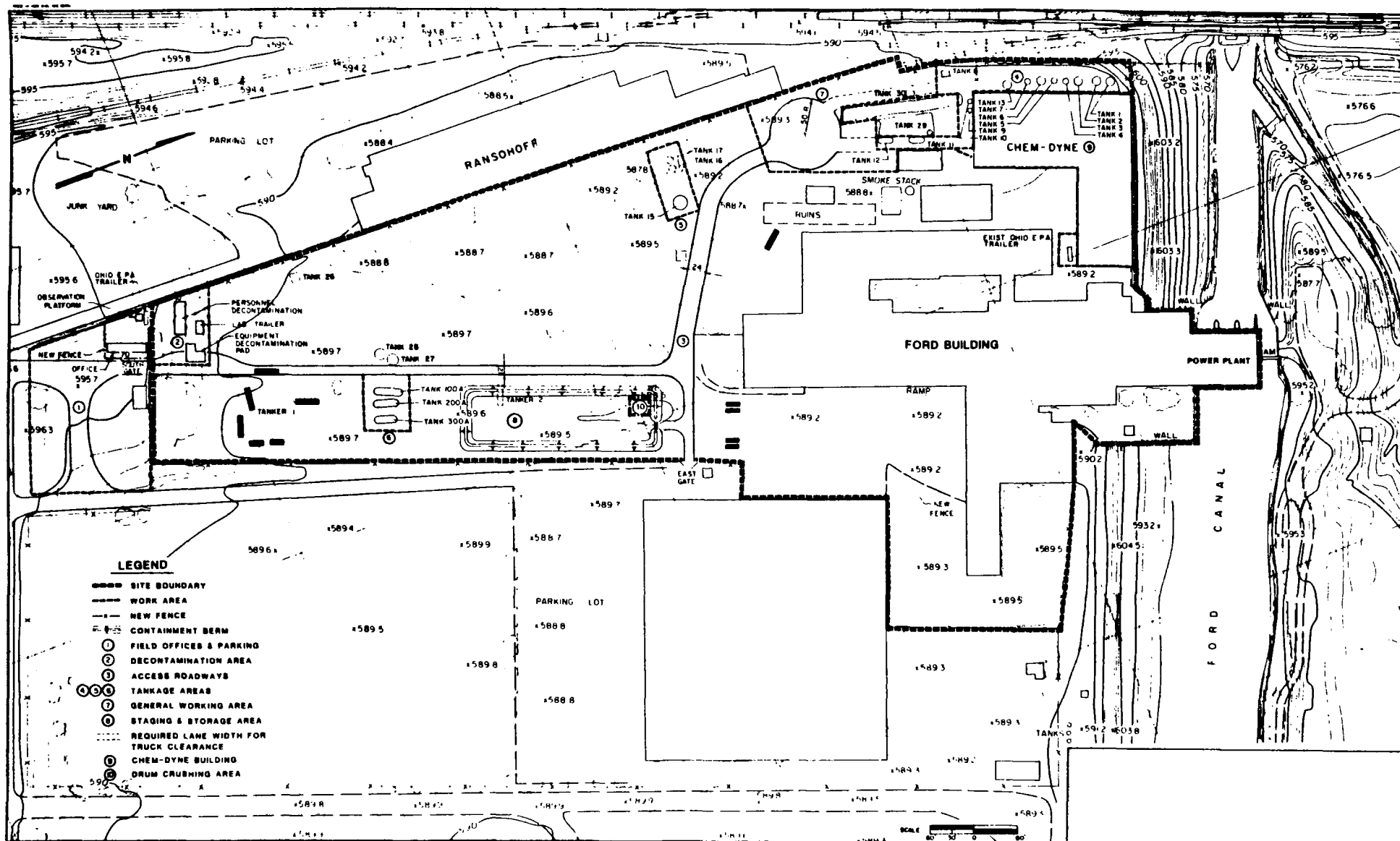
Figure 2
Chem-Dyne Work Area Plan

Figure 3
Chem-Dyne Ambient Air Sampler Locations

MONITORING

The ambient air monitoring network for the cleanup operation at Chem-Dyne consisted of one meteorological station and nine fixed Tenax ® samplers placed around the perimeter of the site (Fig. 3). The Tenax® samplers were pole-mounted, with the sampler inlets at an elevation of 10 ft. The meteorological system, which measured windspeed, wind direction and temperature, was installed at an elevation of 33 ft near the observation platform (outside the perimeter fence). The Tenax® samplers and cartridges were protected from direct sunlight and precipitation by a highly polished metal shield. The shield was open on both ends and the bottom to ensure unrestricted air flow. PEI had previously developed this type of sampler for portions of the Love Canal study and cleanup operations (Fig. 4).

TELEDYNE - HASTINGS
MASS FLOW METER 0 - 100 CCM
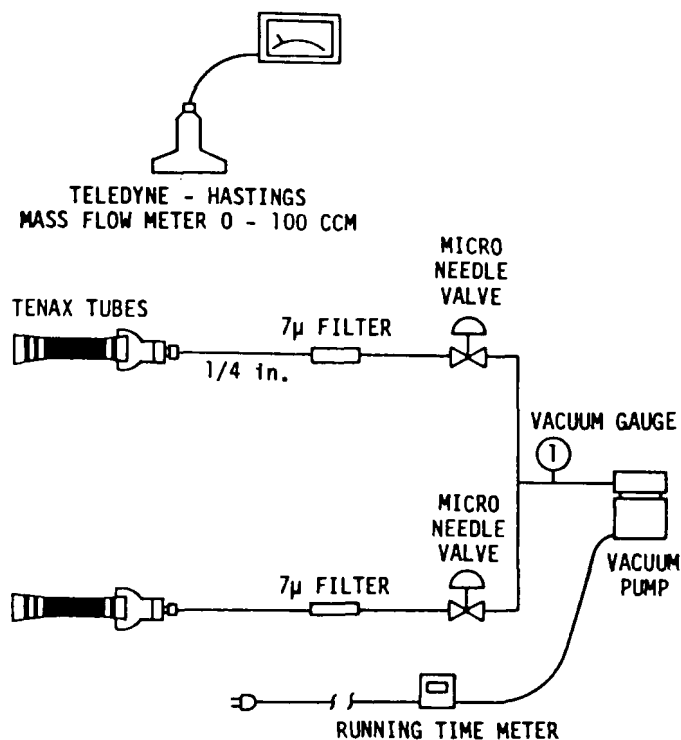
Figure 4
Tenax® Air Sampling System Diagram

The flow through each Tenax® cartridge was controlled by a micrometer needle valve and was measured before and after each sampling period with a Hastings mass flowmeter. The average of the two flow readings was used to determine the air flow rate. The volume of air sampled was determined by multiplying the flow rate by time. Flow was maintained with a vacuum pump capable of pulling a vacuum in excess of 20 in. of mercury. The performance of the flowmeter was verified weekly in the PEI Audit System Verification Laboratory. The Tenax® cartridge was the first component in line on the sampler so the sample would not be in contact with any sample lines or other possible interferences.

Quality Control

To ensure that the data obtained were representative of the emissions during the cleanup activity, PEI operated all nine samplers continuously while cleanup operations were in progress. Operation of all nine sites was necessary to allow for changes in weather conditions. Five samples, one upwind and four downwind, were selected for analysis each day after the meteorological data had been analyzed. Two of the monitoring stations collected two samples each to provide duplicate samples. In addition to the five samples selected for analysis, one of the two sets of collected samples was analyzed daily for quality control purposes.

STATION: CHEM-DYNE
FILE START DATE: 07/16/83
FILE END DATE: 07/17/83
NUMBER OF DAYS: 2
DAYS COVERED IN PRINTOUT: 1-2

WIND DIR	2-7 MPH HRS	%	8-11 MPH HRS	%	12-25 MPH HRS	%	>25 MPH HRS	%	TOTAL HRS	%
N	0	.0	0	.0	0	.0	0	.0	0	.0
NNE	0	.0	0	.0	0	.0	0	.0	0	.0
NE	0	.0	0	.0	0	.0	0	.0	0	.0
ENE	0	.0	0	.0	0	.0	0	.0	0	.0
E	0	.0	0	.0	0	.0	0	.0	0	.0
ESE	0	.0	0	.0	0	.0	0	.0	0	.0
SE	0	.0	0	.0	0	.0	0	.0	0	.0
SSE	0	.0	0	.0	0	.0	0	.0	0	.0
S	0	.0	0	.0	0	.0	0	.0	0	.0
SSW	3	25.0	0	.0	0	.0	0	.0	3	25.0
SW	1	8.3	0	.0	0	.0	0	.0	1	8.3
WSW	0	.0	0	.0	0	.0	0	.0	0	.0
W	1	8.3	0	.0	0	.0	0	.0	1	8.3
WNW	1	8.3	0	.0	0	.0	0	.0	1	8.3
NW	0	.0	0	.0	0	.0	0	.0	0	.0
NNW	0	.0	0	.0	0	.0	0	.0	0	.0
	6	50.0	0	.0	0	.0	0	.0	6	50.0

CALM HOURS   6   50.0

TOTAL HOURS   12   100.0

Wind Rose

The meteorological data (an example of which is shown in Table 1) were delivered to PEI each day along with the Tenax® samples. These data were reduced to hourly averages and presented as a wind rose (example shown in Table 1). The wind rose was then superimposed on the site map to determine which samples were to be analyzed.

Analysis

The field samples were placed in a cooler and delivered to the PEI laboratory. Upon arrival at the laboratory, they were placed in a refrigerator, where they remained until their analysis (within 48 hr of sampling). All Tenax® tubes were sealed in glass culture tubes with Teflon® cap liners. The culture tubes were placed in metal cans and stored in a refrigerator until needed. Strict USEPA-approved chain-of-custody procedures were observed at all times.

Volatile organics were recovered from the Tenax® by thermal desorption and purging with helium into a liquid-nitrogen-cooled nickel capillary trap. The vapors were then introduced into a high-resolution glass GC column where the constituents were separated from each other. Characterization and quantification of the constituents in the sample were accomplished by MS, either by measuring the intensity of the total ion current signal or by extracted ion current profile.

The target compounds specified by the IFB included:

1,2-Dichloroethane
Chloroform
1,1,1-Trichloroethane
Benzene
Carbon tetrachloride
Trichloroethylene
1,1,2-Trichloroethane
Toluene
Perchloroethylene
Chlorobenzene
Meta-dichlorobenzene
Ethyl benzene
P-xylene

Table 2
Example Analytical Data

```
STATION: CHEM-DYNE
FILE START DATE: 07/16/83
FILE END DATE: 07/17/83
NUMBER OF DAYS: 2
DAYS COVERED IN PRINTOUT: 1-2
```

WIND DIR	2-7 MPH HRS	%	8-11 MPH HRS	%	12-25 MPH HRS	%	>25 MPH HRS	%	TOTAL HRS	%
N	0	.0	0	.0	0	.0	0	.0	0	.0
NNE	0	.0	0	.0	0	.0	0	.0	0	.0
NE	0	.0	0	.0	0	.0	0	.0	0	.0
ENE	0	.0	0	.0	0	.0	0	.0	0	.0
E	0	.0	0	.0	0	.0	0	.0	0	.0
ESE	0	.0	0	.0	0	.0	0	.0	0	.0
SE	0	.0	0	.0	0	.0	0	.0	0	.0
SSE	0	.0	0	.0	0	.0	0	.0	0	.0
S	0	.0	0	.0	0	.0	0	.0	0	.0
SSW	3	25.0	0	.0	0	.0	0	.0	3	25.0
SW	1	8.3	0	.0	0	.0	0	.0	1	8.3
WSW	0	.0	0	.0	0	.0	0	.0	0	.0
W	1	8.3	0	.0	0	.0	0	.0	1	8.3
WNW	1	8.3	0	.0	0	.0	0	.0	1	8.3
NW	0	.0	0	.0	0	.0	0	.0	0	.0
NNW	0	.0	0	.0	0	.0	0	.0	0	.0
	6	50.0	0	.0	0	.0	0	.0	6	50.0

CALM HOURS	6	50.0
TOTAL HOURS	12	100.0

Wind Rose

Analytical quality control procedures were followed at all times. These included spiked tubes and blanks and instrument tuning according to IFB specifications and the procedures outlined in the PEI Laboratory Quality Assurance Plan.

After completing the analyses, PEI delivered written reports to the prime contractor's Quality Assurance Supervisor during the next visit to the site. Results were reported in mg/m^3 (ng/ml) for easy comparison with published TLV tables. If a value greater than 10% of the TLV was observed, the prime contractor's Quality Assurance Supervisor was notified by telephone.

Except for occasional electrical current interruption or pump malfunction (quickly remedied with spare parts by PEI's on-site technician), the project proceeded smoothly for more than 120 work days (approximately 180 calendar days). Some concern was expressed over "channeling" of air currents due to the proximity of two samplers to long, multistory buildings. Some alternative locations were proposed. Since none offered better conditions, the samplers remained where originally placed.

When two security guards became ill one night while the site was inactive, round-the-clock sampling was proposed. It was determined, however, that the episode was unrelated to emissions from the site and sampling continued to be conducted during working hours only.

CONCLUSIONS

An example of the analytical results is shown in Table 2. Not once during the entire project did analyses indicate that air levels of any of the target compounds exceeded 10% of the applicable TLV. Even though levels of target and other compounds remained low relative to their respective TLVs, this monitoring technique does not replace direct measurements by OVA or photometric methods which are critical to on-site personnel health and safety management.

MEASUREMENT OF VOLATILE ORGANIC EMISSIONS FROM SUBSURFACE CONTAMINANTS

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INTRODUCTION

Organic subsurface contaminants present a potential for human exposure via the pathways of both air and water. The migration of volatile organic compounds (VOCs) from contaminated soils or groundwater into the air represents a potentially major source of exposure which has not yet been adequately assessed.

To assess the exposure potential of this pathway, a method is needed to directly measure gas emission rates from the contaminated material or overlying soil. It should be emphasized that the need is for a measure of the gas emission rate, not just a gas concentration.

The emission rate data would permit an exposure assessment through the use of existing models and define the need to control gas emissions from subsurface contamination sites or at hazardous waste facilities. Application of this measurement method may include calculation of losses of volatile organic compounds from storage tanks, pipelines, surface spills and/or ponds as well as direct emissions from surface impoundments, land treatment sites and landfills.

The USEPA Environmental Monitoring Systems Laboratory has been sponsoring research to select, document and demonstrate an appropriate method for directly measuring gas emission rates from contaminated soils and/or groundwater for exposure assessment purposes. Based upon a review of the relevant literature, the enclosure emission measurement technique was selected as the method of choice. A draft protocol for the technique has been completed. It presents the principle of the method, descriptions of the equipment, calibration procedures, quality assurance and quality control procedures and an operational protocol.

To date, the method has been demonstrated at several field sites. Parametric tests were performed to evaluate the effect of specific variables on the measured emission rates. In the second phase of the study, laboratory studies have investigated the effect of environmental and operating variables on the volatilization and emission rate of organic compounds in order to verify the validity of the method. The end product of this research will be a protocol for use in measuring volatile organic compound emission rates from contaminated soils and/or groundwater.

This paper presents the results of field measurements at a spill site. Included are an assessment of emissions from the site, an evaluation of the effect of specific operating variables on the measured emission rates, an evaluation of the appropriateness of the statistical sampling procedure for area sources and an analysis of the sources of variability in the method.

DESCRIPTION OF METHOD

The emission isolation flux chamber is a device used to make a direct emission measurement. The enclosure approach has been used by researchers to measure emission fluxes of sulfur and volatile organic species.[1,2,3] The approach uses an enclosure device (flux chamber) to sample gaseous emissions from a defined surface area. Clean dry sweep air is added to the chamber at a fixed controlled rate. The volumetric flow rate of sweep air through the chamber is recorded, and the concentration of the species of interest is measured at the exit of the chamber. The emission rate is expressed as:

$$E_i = C_i R/A \qquad (1)$$

where

E_i = emission rate of component i, $\mu g/m^2$-sec
C_i = concentration of component i in the air flowing from the chamber, $\mu g/m^3$
R = flow rate of air through the chamber, m^3/sec
A = surface area enclosed by the chamber, m^2

All parameters in Equation 1 are measured directly.

A diagram of the flux chamber apparatus used for measuring emission rates is shown in Figure 1. The sampling equipment consists of a stainless steel/acrylic chamber with impeller, ultra high purity sweep air and rotameter for measuring flow into the chamber and a sampling manifold for monitoring and/or collection of the specie(s) of interest. Concentrations of total hydrocarbons are monitored continuously in the chamber outlet gas stream using a portable flame ionization detector (FID) and/or photoionization
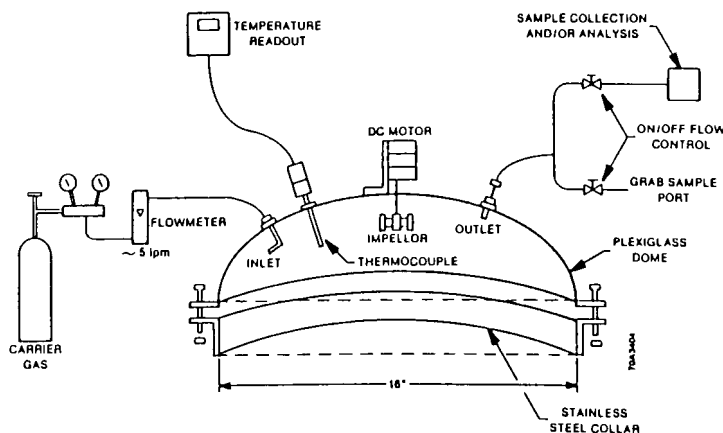
Figure 1
Cutaway Side View of Emission Isolation Flux Chamber and Sampling Apparatus

detector (PID)-based analyzers. Samples are collected for subsequent gas chromatographic (GC) analysis once a steady-state emission rate is obtained. Air and soil/liquid temperatures are measured using a thermocouple.

To determine the emission rate for a source of much greater area than that isolated by the flux chamber, a sufficient number of measurements must be taken at different locations to provide statistical confidence limits for the mean emission rate. The area sources measured were gridded (30 ft × 75 ft) and a minimum of six measurements (when possible) to account for spatial variability. Additionally, a single point was selected as a control point to define temporal variability. On-site GC analyses were performed for all flux chamber measurements, and several canister samples were collected for each area to allow off-site detailed GC analysis. Prior to using the chamber, blank and species recovery data were obtained.

FIELD TEST

The field test took place at a Marine Corps helicopter facility in Tustin, California. The spill site was an abandoned practice firefighting area where JP-4 aviation fuel had permeated the local soil resulting in a hydrocarbon lens at the surface of the saturated zone. Much of the contaminated surface soil has been excavated and backfilled with sand. The estimated area of the contaminated groundwater plume is 45,000 ft^2. The overlying soil in this area is primarily sandy silt with a large clay fraction. Depth to groundwater is nominally 16 ft below land surface. Product was being recovered from the groundwater in the area at a rate of 50 gal/month.

Field tests involved gridding the area to be measured, dividing the gridded area into two distinct zones (upper and lower) and conducting the flux chamber measurements at randomly selected gridpoints. Following the first set of flux chamber measurements, a second set of measurements was made to evaluate six variables associated with the flux chamber design and/or operation. The variables assessed during this parametric study are listed in Table 1. The approach used to conduct the parametric study was to make a measurement at the baseline conditions, followed by a measurement at the modified condition. A set of six paired measurements was typically made at a number of different gridpoints.

Table 1
Parametric Test Studies of the Flux Chamber

Parameter	Equipment or Procedural Modification	Result of Modification
Chamber geometry	Use of flat topped, 23L chamber in place of typical domed, 31L chamber	Chamber geometry varied
Chamber opacity	Chamber covered with 4-5 layers of thin, black polyethylene sheeting	Chamber blocked from all solar radiation
Chamber temperature	Heating coil with temperature controller placed inside chamber	Chamber maintained at 10°C above typical chamber temperature
Relative humidity	Sweep air passed through an impinger of DI water	Sweep air relative humidity increased
Sweep air flow rate	Sweep air flow rate decreased	Sweep air flow rate 1/3 of baseline rate (1.1 L/min vs. 3.2 L/min)
Impellor rate	Chamber operated with impellor off	Mixing characteristics of chamber varied

A statistical analysis of the data was performed to investigate the effect of the variables (chamber geometry, impeller rate, chamber opacity, relative humidity, sweep air flow rate and temperature) on the VOC emission rates measured in the field. Emission rates were calculated from the sampling and analytical data as shown above (Eq. 1).

Table 2
Comparison of Air and Liquid Samples with JP-4 Composition

Primary Components of JP-4[a]	Liquid Sample Well #24[b]	Headspace Sample Well #24[b]	Flux Chamber Sample Grid Point 28[b]
n-Pentane		x	x
2/3-methylpentane		x	x
n-hexane		x	
methylcyclopentane	x	x	x
cyclohexane	x	x	x
2/3-methylhexane	x	x	x
n-heptane	x	x	x
methylcyclohexane	x	x	x
toluene	x	x	x
2/3-methylheptane	x	x	x
n-octane	x	x	x
o-xylene	x	x	x
n-nonane	x	x	x
1,2,3 trimethyl-benzene	x	x	x
n-decane	x	x	x
n-dodecane			
n-tridecane			

[a]Compounds present at greater than 1 percent by weight in JP-4 aviation fuel

[b]Analysis by capillary GC-FID/PID

A paired t-test was used to test the hypothesis that a given variable influenced the measured emission rate. Analysis of covariance was used to account for the fact that the temperature in the chamber varied from one measurement to the next. This treatment made it possible to differentiate between the random scatter and temperature trends in the paired measurement data. In this manner, the error variance in the random scatter was minimized making it easier to identify the effects of the variables of interest.

DISCUSSION OF RESULTS

The compounds identified during the emission measurements were compared against the major components of the JP-4 aviation fuel, the contaminant layer and the vapor space in one of the exploratory wells. As shown in Table 2, the major components of JP-4 aviation fuel were identified in the contaminant layer, well vapor space and emissions measured with the flux chamber. This fingerprint indicates that the emissions measured were the result of the aviation fuel.

Air temperatures in the flux chamber varied over the course of a day, with changes in the ambient temperature (90°-115°F). The emission rates measured at a single location were correlated with the air temperature within the flux chamber over the course of day. The observed trends in the data are shown in Figure 2. This correlation was used to correct the measured emission rates to values which would be expected if all measurements had been made at an average air temperature within the chamber.

There was typically a difference between the ambient air temperature and the air temperatures measured within the chamber. This difference typically ranged from 2° to 18°F. Soil temperatures were difficult to measure accurately; however, the values measured indicated minimal differences (<4°F) between the inside and outside of the chamber. Soil temperatures did vary over the course of the day but to a lesser extent than the air temperature. The variation in soil temperature was typically less than 9°F.
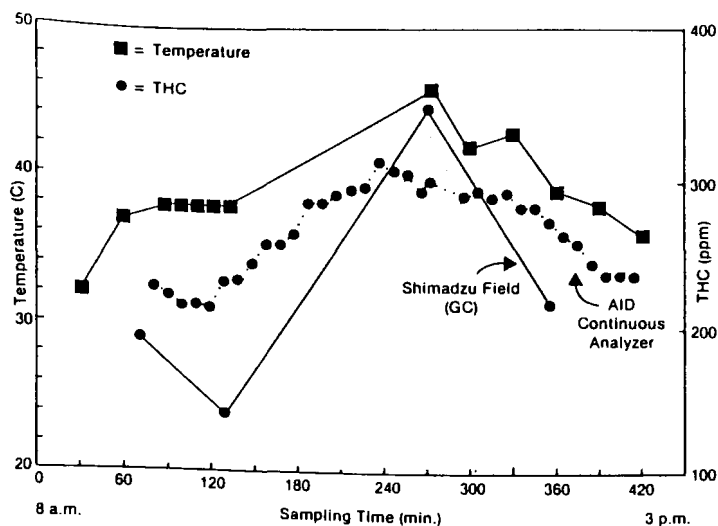
Figure 2
Variations in Temperature and Total Hydrocarbon vs. Time
at a Single Sampling Location
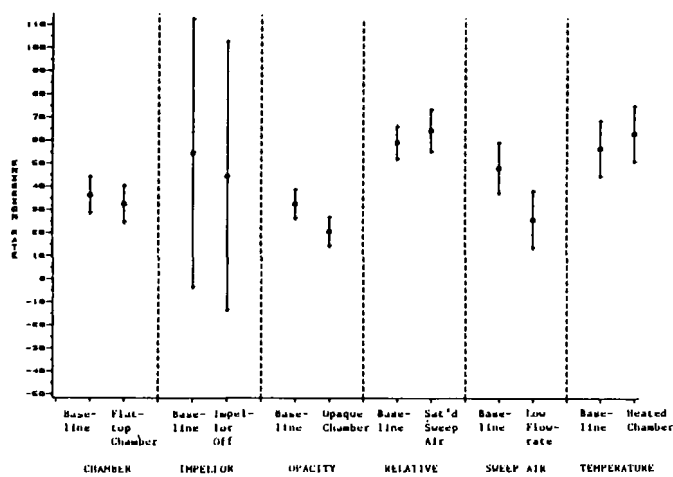
Figure 3
Mean Emission Rates per Variable Tested

The mean corrected emission rates for each parameter tested are shown in Figure 3 with the corresponding baseline data. The error bars represent the 95% confidence interval. The large error bars present for the impeller rate tests are due to only two tests being performed for this variable versus six tests for each of the other variables. The data shown in Figure 3 are presented in Table 3.

The statistical significance of each parameter is presented in Table 4. At the 95% probability level, only opacity and sweep air flow rate were significant. At the 60% probability level, all variables except chamber geometry were significant. No statistical significance means that there was not enough evidence in the data to conclude a statistical significance.

Two different flux chamber geometries were tested, one having a flat acrylic top and the other (baseline condition) a domed acrylic top. Either of these designs is expected to be suitable, with the use of an impeller for mixing. Tests run without the impeller showed a decrease in the measured emission rate. Additionally, a greater amount of variability was observed in the concentration levels in real-time. For these reasons, it is suggested that an impeller be used to assure proper mixing for any given chamber geometry.

Significant differences in the measured emission rate were noted when incoming sunlight was shielded from the chamber. Internal air temperatures were also lowered; however, the change in air temperature does not account for the total effect observed. As

previously stated, the soil temperatures were difficult to measure. The shielded sunlight may cause a change in soil temperature at the surface which could not be measured. This effect will be investigated in future studies.

The relative humidity of the air inside the flux chamber will vary depending upon the soil conditions. Baseline operation of the flux chamber is with dry sweep air. Relative humidities from 10 to 95% have been observed. Condensation can form in the chamber at relative humidities greater than 70%. During the tests, an increase in relative humidity to 60% was obtained by passing the sweep air through a bubbler. No condensation was observed in the chamber at these relative humidities, and no effect on the measured emission rate was noted. Dry sweep air whould be used for flux chamber operation.

The flux chamber is routinely operated at sweep air flow rates of 3-5 l/min. The flow rate can be lowered when emission rates are low in an attempt to reduce the dilution and allow analytical detection. For these tests, the flow rate was reduced to 1 l/min. This change significantly reduced the emission rate measured. At this time, it is not known if this effect is the result of changing the air phase concentration or the mixing at the air-soil interface. This effect does have important implications for the sampling methodology and is being investigated in Phases II and III of the project.

The chamber air temperature showed significant trends with emission rate for the eight-hour test (as previously shown), was significant at the 60% probability level for the parametric test, but was not significant at the 95% probability level. It is expected that temperature can have an effect on the measured emission rate. However, the air temperature will be a variable which cannot be controlled. For this reason, it is important that temperature be monitored during measurements. Additional studies will investigate the dependence of the emission process on temperture so that an appropriate comparison can be made between measurements at different temperatures.

The variability in the measured emission rates was due to a variety of factors, as shown in Table 5. Only one-third of the variability was due to sampling and analytical considerations, i.e., under the control of the experimenter. As shown, 17% of the total sampling variability was attributed to spatial considerations while 24% of the total variability was attributed to temporal considerations. As shown, 25% of the total variance was eliminated by correcting for temperature. This supports the fact that temperature is a significant variable.

One of the objectives of this field demonstration was to determine if the average of six individual flux chamber measurements adequately represents the emission rate from an entire area source. As a test of this hypothesis, the average emission rate from various subsets of six points was compared to the overall average emission rate. Emission data from a single day were randomly selected for each of the 12 gridpoints measured. The total variability of the randomly chosen data includes spatial, temporal and sampling/analytical variability (data were corrected to an average temperature). The summary statistics for the 12 values chosen were as follows:

overall mean (μg-C/m²-sec) 44.6
standard deviation (μg-C/m²-sec) 15.9
coefficient of variation (%) 35.5

All possible subsets of size six were chosen from the 12 adjusted emission rate values; means, standard deviations and coefficients of variations were computed for each. Of the 924 subset means, 99.8% were within 25% of the overall mean and 66% were within 10% of the overall mean. The overall mean was within the 95% confidence intervals of 99.8% of the subset means. Coefficients of variations ranged from 13% to 51% for the subsets. Thus, the authors believe that the procedure was adequate in calculating an average emission rate representative of the entire area.

The overall emission rate estimate must not be confused with the population emission rate. A population emission rate average

Table 3
Table 3
Analysis of Covariance Results for Examining the Effects of Various Factors on Measured Emission Rate

Test Condition		No. of Data Points	Emission Rate $(\mu g\text{-}C/m^2\text{-}sec)$ Adjusted Mean[a]	Std. Error	Statistical Significance[b]	Residual Std. Dev. $(\mu g\text{-}C/m^2\text{-}sec)$[c]	$R^2 (\%)$[d]
Chamber Geometry	Baseline	6	36.3	3.01	No	7.17	82.7
	Flattop Chamber	6	32.4	3.01			
Impeller Rate	Baseline	2	54.8	4.59	No	6.50	96.0
	Impeller Off	2	44.8	4.59			
Opacity	Baseline	6	33.1	2.39	Yes	5.65	93.1
	Opaque Chamber	6	21.2	2.39			
Relative Humidity	Baseline	6	60.4	2.74	No	6.62	95.9
	Sat'd Sweep Air	5	65.8	3.30			
Sweep Air Flow Rate	Baseline	7	49.4	4.49	Yes	11.71	82.4
	Low Flow Rate						
Temperature	Baseline	6	57.9	4.70	No	11.5	91.8
	Heated Chamber	6	64.6	4.70			

a. With the exception of the temperature test series data, mean emission rates were corrected for the concomitant variable (covariate) of average air temperature in the chamber.

b. Based on the analysis of covariance results, does the test condition have a significant effect on measured emission rate at the 95% probability level $\alpha = 0.05$)?

c. The residual standard deviation provides an estimate of emission rate measurement repeatability (a measure of differences that are likely to occur between repeat measurements of the same grid point under the same conditons). This is an indirect estimate of repeatability that depends on the accuracy of the model (errors in the model tend to increase the residual standard deviation). A better way to estimate repeatability, therefore, is to do repeat tests.

d. The R^2 statistic measures the amount of variation in emission rate which has been explained by the terms in the model (grid point, test condition, and average temperature in the chamber).

Table 4
Significance Levels of Tustin Lower Level Sampling Data

Test Series	T-Value[*]	Probability of Greater T[†]	Statistical Significance[‡]
Chamber Geometry	0.907	0.416	No
Impeller Rate	1.542	0.366	No
Opacity	3.401	0.027	Yes
Relative Humidity	−1.24	0.303	No
Sweep Air Flow Rate	3.797	0.013	Yes
Temperature	1.000	0.364	No

* The student's T value for testing the hypothesis that the test condition (baseline vs. non-baseline) does not have a significant effect on emission rate (adjusted for temperature).

† Probability of a greater absolute T value assuming adjusted emission rate differences follow a normal distribution.

‡ Based on the analysis of covariance results, does the test condition have a significant effect on measured emission rate at the 95% probability level ($p = 0.05$)? Given a conclusion of a statistical difference, there is a 5% probability that we are wrong.

Table 5
Components of Variability for Flux Chamber Measurements

Source of Variability	Variance Component[*]	% of Total Variance	% of Total Minus Temperature Variance
Temperature in the Chamber	132.5	26.3	—
Grid (Sampling Location)	86.7	17.2	23.3
Temporal (Day-to-Day)	121.0	24.0	32.6
Sampling/Analytical	163.8	32.5	44.1
TOTAL	504.0	100.0	100.0

* Variance components are equal to standard deviations squared and thus have units which are the squares of that used for the measured emission rates ($\mu g\text{-}C/m^2\text{-}sec$).[1]

●The sampling and analytical variability associated with the flux chamber measurements are estimated at 33%
●The statistical sampling approach does appear to result in an average emission rate representative of the entire area

These findings are not considered to be definitive but will provide the direction for additional study.

DISCLAIMER

would require complete continuous measurements with time over the entire area. This, of course, is not possible. For this reason, probability (random) sampling in space and time are employed when determining the average emission rate values.

The average emission rate measured at the spill site was 0.24 μg-C/m²-sec for the upper level and 41.6 μg-C/m²-sec for the lower level. These emission rates correspond to a daily emission rate from the areas of 0.18 kg-C/day. Extrapolated to a yearly value, this is an emission rate of 65 kg-C/year of total hydrocarbons.

CONCLUSIONS

The flux chamber field tests have provided insights to the variables which affect the measurement method, the variability associated with the sampling procedure and the appropriateness of the statistical sampling procedure for area spills. Specifically:

●Measured emission rates do vary with air temperature, and it is possible to adjust the values to an average temperature, thereby lowering the variability associated with the measurements
●Measured emission rates decreased when sweep air flow rate was decreased
●Measured emission rates decreased when sunlight was shielded from the chamber
●Measured emission rates were not affected by changes in chamber geometry and relative humidity

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ON-SITE AIR MONITORING CLASSIFICATION BY THE USE OF A TWO-STAGE COLLECTION TUBE

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INTRODUCTION

The USEPA's Environmental Response Team (ERT) was established in October, 1978 to provide technical assistance to Federal On-Scene Coordinators (OSC), Regional Response Team (RRT), National Response Team (NRT), USEPA Headquarters/Regional Offices and other government agencies in the area of environmental emergency issues such as chemical spills and uncontrolled hazardous waste sites.

In this paper, the authors describe the two-stage air sampling tube developed jointly by ERT and Oil and Hazardous Materials Spills Branch, Edison, New Jersey. The project was based on state-of-the-art techniques with the objective of developing a convenient screening media for air samples at sites where unknown and multiple contaminants may be present. The authors describe the tube development, sampling rates and method of analysis.

PROJECT SCOPE OF WORK

Imagine a 20-acre site anywhere in the country with 5,000 to 10,000 unidentified 55-gal drums and four unlined waste lagoons containing unidentified liquids adjacent to a housing development. You have been asked to conduct an emergency air monitoring program. What collection medium would you select? Charcoal? Tenax-GC? Florisil? Silica gel? What sample flowrate would you use (10 cc/min, 50 cc/min, 100 cc/min. 1 l/min, 2 l/min)? What would be the appropriate sampling volume? What is the minimum analytical turnaround time? What is the appropriate analytical protocol? What would be the total number of samples collected per station? These are just a few of the questions one would ask oneself if given this assignment. Obviously, the assignment becomes less difficult with more information to evaluate. A multistage tube was developed to provide a quick profile of compounds encountered at a typical hazardous waste site.

The fastest way to get a rapid qualitative and quantitative characterization of an unknown mixture is by gas chromatography/mass spectrometry (GC/MS). Solid sorbent media are most convenient for field work. Thermal desorption with cryogenic trapping requires minimal sample preparation and permits a very "clean" sample injection onto the GC/MS analytical equipment.

To minimize the cost and development period, the project was originally restricted to three candidate tube configurations, each having three separate stages:
- *Candidate Tube A*—To consist of a polyurethane foam first stage, Tenax-GC second stage and an activated carbon third stage
- *Candidate Tube B*—To consist of a polyurethane foam first stage, Chromosorb 102 second stage and an activated carbon third stage
- *Candidate Tube C*—To consist of a polyurethane foam first stage, Porapak S second stage and an activated carbon third stage

EVALUATION PROCESS

The evaluation was made in three phases. First, a preliminary study was conducted to ascertain the thermal desorption characteristics of the candidate sampling media and to optimize the thermal desorber and GC/MS conditions. The results of the preliminary investigation indicated that polyurethane foam, Porapak S and activated charcoal were not suitable media for thermal desorption. These media were excluded from further study. The candidate media not rejected in Phase 1 (Chromosorb-102 and Tenax-GC) were spiked directly with a liquid solution of the chemicals shown in Table 1.

Table 1
Liquid Solution Used for Media Evaluation

Material	Quantity (μg)	% of TLV for a 1-l Air Sample
Isopropyl alcohol	39	4.0
Methyl isobutyl ketone	16	7.8
Ethylbenzene	17	3.9
Aniline	1.0	10
2,4-Dichlorophenol	0.66	---
Naphthalene	1.0	2.0
Chlordane	1.0	200
Aroclor 1254	1.0	200
n-Nitrosodimethylamine	0.067	---
bis(2-Chloroethyl) ether	0.066	---
Tricresyl phosphate (Technical)	0.60	600*

*Based on TLV for triorthocresyl phosphate (0.1 mg/m³)

The results of the spiking study are summarized in Tables 2-5.

Table 2
Spiking Study—Tenax-GC
(% Recovered at 250°C Desorption)

	Spike 1	Spike 2	Spike 3	Mean
Isopropyl alcohol	55	60	64	60
Methyl isobutyl ketone	79	82	89	83
Ethylbenzene	95	95	83	91
Aniline	68	70	88	75
2,4-Dichlorophenol	100	160	180	150
Naphthalene	51	79	88	73
Chlordane	62	88	100	83
Arochlor 1254	87	88	110	95

Table 3
Spiking Study—Chromosorb 102
(% Recovered with 150°C Desorption)

Material	Spike 1	Spike 2	Spike 3	Mean
Isopropyl alcohol	96	84	88	89
Methyl isobutyl ketone	92	110	95	99
Ethylbenzene	84	98	76	86
Aniline	23	34	46	34
2,4-Dichlorophenol	37	53	27	39
Naphthalene	33	24	7	21
Chlordane	ND*	11	5	5
Arochlor 1254	ND*	10	5	5

*Non-detectable

A separate spiking study was conducted for n-nitrosodimethyl-amine and bis (2-chloroethyl) ether. In this study, 100 mg sections of Tenax-GC and 200 mg sections of Chromosorb 102 were spiked with 1.0 μl of a dodecane solution containing 0.844 mg of n-nitrosodimethylamine and 1.22 mg of bis (2-chloroethyl) ether/ml of solution. The resultant spike levels were 0.844 and 1.22 μg, respectively. The results of the spiking stidy indicate good recovery from Tenax-GC, and somewhat excessive recovery from Chromosorb 102 (Tables 4 and 5).

Table 4
Spiking Study—Tenax-GC
(% Recovered at 250° C Desorption)

Material	Spike 1	Spike 2	Spike 3	Mean**
n-Nitrosodimethylamine	99	94	39 (void)	92
bis (2-Chloroethyl) ether	120	96	43 (void)	110

**Excluding Spike 3, which was voided due to determinate error (cryogenic trap liquid nitrogen level was low).

Table 5
Spiking Study—Chromosorb 102
(% Recovered at 150° C Desorption)

Material	Spike 1	Spike 2	Spike 3	Mean
n-Nitrosodimethylamine	200	330	340	290
bis (2-Chloroethyl) ether	240	310	330	290

The results of the spiking study indicated that the Tenax-GC section should precede the Chromosorb 102 section in the final tube configuration.

Based on the results from Phase 2, a tube was selected for further evaluation. This evaluation consisted of generating known concentrations of the same materials at different relative humidities (20, 50 and 90%) in a stainless steel calibration chamber at 25° C. Duplicate samples were collected at three flow rates (10, 20 and 50 cc/min) and analyzed by thermal desorption/cryogenic trapping/GC-MS to evaluate overall recovery for the sampling and analytical system. The following six tables summarize the results of the Phase 3 testing:

Table 6
Total Recovery at 20% Relative Humidity
(% of Actual Concentration)

Nominal Flowrate:	10 ml/min		20 ml/min		50 ml/min	
	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2
Isopropyl alcohol	170	210	82	73	130	200
Methyl isobutyl ketone	170	190	97	96	180	160
Ethylbenzene	250	180	150	170	180	250
Aniline	160	310	200	210	180	110
2-4-Dichlorophenol	4.9	84	56	87	15	<3 7
Naphthalene	110	130	100	110	130	120

Table 7
Total Recovery at 50% Relative Humidity
(% of Actual Concentration)

Nominal Flowrate	10 ml/min		20 ml/min		50 ml/min	
	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2
Isopropyl alcohol	Void*	140	240	170	190	190
Methyl isobutyl ketone	Void	130	110	130	88	100
Ethylbenzene	Void	150	140	140	120	140
Aniline	Void	32	21	21	23	6
2,4-Dichlorophenol	Void	100	149	150	63	11
Naphthalene	Void	89	⁻9	89	85	110

*Sample voided—faulty valve on sampling pump prevented drawing air through tube

Table 8
Total Recovery at 90% Relative Humidity
(% of Actual Concentration)

Nominal Flowrate	10 ml/min		20 ml/min		50 ml/min	
	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2
Isopropyl alcohol	Void*	41	44	90	46	41
Methyl isobutyl ketone	Void	120	79	92	97	100
Ethylbenzene	Void	110	120	130	110	100
Aniline	Void	86	15	6.0	33	49
2,4-Dichlorophenol	Void	150	16	7	82	34
Naphthalene	Void	64	56	23	60	69

*Sample voided—faulty valve on sampling pump prevented drawing air through tube.

A separate calibration chamber test was conducted in which tubes were challenged at 50% relative humidity only with n-nitrosodimethylamine (challenge concentration: 0.844 mg/m3) and bis (2-chloroethyl) ether (challenge concentration: 1.22 mg/m3).

Table 9
Recovery from Tenax-GC Section at 50% Relative Humidity
(% of Challenge Concentration Indicated by Sample)

Nominal Flowrate	10 ml/min		30 ml/min		50 ml min	
	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2
n-Nitrosodimethylamine	100	97	83	Void* 34		79
bis (2-Chloroethyl) ether	93	120	84	Void 100		91

*Sample voided—faulty valve on sampling pump presented air being drawn through tube.

Neither material was detected in any of the Chromosorb 102 sections.

Because Arochlor 1254 and chlordane failed to volatize properly in the stainless steel chamber, separate tests were run by

evaporating those materials from a glass wool plug into an ambient humidity airstream. "Challenge" concentrations were measured by simultaneous sampling of the streams by NIOSH Methods S-244 and S-278:

Table 10
Arochlor 1254 Recovery from Tenax-GC Section
at 54% Relative Humidity

Sample Number	Sampling Period (min)	Sample Volume (l)	Challenge ([mg/m³])	Found (μg/sample, [mg/m³])	Recovery (%)
TCA-1	100	4.76	[1.6]	7.5 [1.6]	100
TCA-2	100	4.82	[1.6]	7.5 [1.5]	94
TCA-3*	100	4.51	[1.6]	0.4 [0.09]*	6*

*Inspection of TI chromatogram strongly suggests that there was leakage loss during thermal desorption and cryogenic trapping. "Background" peaks found in blanks and other samples were present at much lower intensity in Sample TCA-3.

No detectable amounts of polychlorinated biphenyl were found in any of the Chromosorb 102 sections.

Table 11
Chlordane Recovery from Tenax-GC Section at 50% Relative Humidity

Sample Number	Sampling Period (min)	Sample Volume (l)	Challenge ([mg/m³])	Found (μg/sample, [mg/m³])	Recovery (%)
TCC-1	105	4.74	[0.22]	0.6 [0.13]	59
TCC-2*	105	4.93	[0.220	0.1 [Void]*	Void*
TCC-3	105	4.91	[0.22]	0.4 [0.82]	37

*Sample TCC-2 voided due to data system lockup preventing execution of GC oven temperature program.

No detectable amounts of chlordane were found in any of the Chromosorb 102 sections.

Like many short-term projects based on state-of-the-art techniques, the scope of work was modified as the results from the evaluation phase were generated. In fact, the finished prototype consists of a two-stage collection tube with a Tenax-GC first stage and a Chromosorb 102 second stage.

The study also indicated that the optimum flowrates for the selected analytical method were 50 ml/min for 10 l and 10 ml/min for 1 l. Actual field experience, however, has indicated that the optimum flowrates are 20 ml/min for 5 to 6 l, and 50 ml/min for 10 to 12 l. It was apparent from the study that all the chemicals identified in the Tube Evaluation Process section of this paper will not be collected by the two-stage tube. Such chemicals as tricresyl phosphate, isopropyl alcohol, chlordane, Arochlor 1254 and naphthalene may not be easily identified during field activities.

RECOMMENDED SAMPLING METHOD

Apparatus

•Air sampling pump capable of drawing air through the two-stage sampling tube at flowrates ranging from 10 to 50 ml/min against vacuums ranging from 0.5 to 5.0 cm of water. The sampling pump must be calibrated before and after use with a representative sample tube in place.

•Two-stage glass sampling tubes flame-sealed at both ends, 8-mm O.D. and 6-mm I.D., 25 cm long, containing two sorbent sections retained by glass wool:
-Front section: 100 mg of Tenax-GC, 20/35 mesh, Soxhlet extracted first for 6 hr with pentane (Mallinckrodt Nanograde), then for 6 hr with methanol (J.T. Baker, HPLC Grade), then purged at 300° C with dry nitrogen at a flowrate of 30 ml/min for 12 hr.

-Back section: 200 mg of Chromosorb 102, 20/40 mesh, Soxhlet extracted in the same manner as the Tenax-GC, then purged at 250° C with dry nitrogen at a flowrate of 30 ml/min for 12 hr.
-The sections are centered between the middle of the glass tube and the beginning of the flame-sealed taper at each end.

Sample Collection

•Immediately before sampling, break the ends of the tube to provide at least a 2-mm opening on each end.
•The Chromosorb 102 section, which has a fine, bead-like texture, is the back section of the tube and is positioned nearest the pump. Air should not be passed through any hose or tubing before entering the front (Tenax-GC) section, which has a granular appearance.
•Collect at least two samples differing in volume by an order of magnitude. Sampling at 10 ml/min for 100 min would yield a sample volume of 1.0 l, and sampling at 50 ml/min for 200 minutes would yield a sample volume of 10.0 l.
•The temperature and pressure of the atmosphere being sampled should be recorded.
•The tubes should be capped immediately after sampling with the supplied plastic caps. No substitutes are acceptable.
•At least one "blank" sample (ends broken and then capped immediately) must be submitted with each set of samples collected at each location sampled.
•Because certain solvent vapors can penetrate the polyethylene caps, and because the analytical method is extremely sensitive, every precaution should be taken to prevent exposing even capped tubes to organic vapors. Placing the tubes in a glass jar with a screw cap immediately after sampling is recommended. Tubes must never be packed or transported in the same container as bulk samples.

RECOMMENDED ANALYTICAL METHOD

Apparatus

Thermal Desorber/Cryogenic Trap/
Capillary GC-MS System
A 7.5-cm long, 7.0-cm wide, 5.0-cm tall aluminum block with heater cartridge controlled by a rheostat is used for the thermal desorption. The 5.0-cm height is formed by two 2.5-cm thick blocks hinged along one side with facing surfaces machined to ensure good contact for maximum heat transfer. The block assembly has an 8 cm diameter hole drilled through the center along the 7.5-cm length to accommodate the sample tube.

The desorbed vapors in the helium carrier pass through a nickel tube into a heated (250° C) six-port Valco valve then into a 1 m long, 0.1 cm I.D. nickel tube formed into a coil and immersed in liquid nitrogen. The trap is wrapped with nichrome wire to effect rapid heating. During the thermal desorption, helium exiting the cryogenic trap is plumbed through the Valco valve to a venting port, and the chromatograph column carrier gas is plumbed through the valve to a heated line connected directly to the gas chromatograph column inlet. When desorption is complete, the valve is rotated to pass the carrier gas through the cryogenic trap, whose exit simultaneously is connected through the valve to the port leading to the chromatograph column. The trap then is removed from the liquid nitrogen bath and its heater switched on so trapped vapors are quickly volatilized and carried into the column. The column exit is connected directly to the mass spectrometer inlet.

Nickel tubing (0.1 cm I.D.) wrapped with nichrome wire and heated to 250° C is used for all connections through which desorbed vapors pass.

GC-MS Column and Conditions
Capillary Column: Hewlett-Packard, SE54, 25 m long, 0.31 mm I.D.
Temperature Program: Isothermal at 0° C for 2 min, then increase at 6° C to 280° C and hold.

Analysis of Samples

Thermal Desorption of the Tenax-GC Section

Score the tube in the center with a sharp file and break in half. Cap the exposed end of the Chromosorb 102 section and return to storage for later analysis. Scribe the flame-sealed end of the Tenax-GC section 1 cm from the end of the taper (on the cylindrical portion) and break evenly. With the trap in liquid nitrogen and the valve in the thermal desorption position, connect one end of the tube by means of an 0.8 cm Swagelok fitting with Teflon ferrule to the heated line entering the valve assembly. Again, using an 0.8 cm Swagelok fitting with Teflon ferrule, connect the helium purge line to the other end of the tube. The helium flow should be 30 ml/min. Open the desorber block (preheated to 250° C), place the tube in the channel, then close the block. Desorb the sample for 10 min at 250° C before rotating the valve, removing the liquid nitrogen bath and turning on the trap heater. The carrier gas flowrate should be in the range of 1 to 2 ml/min depending on the capillary column.

Analysis of Chromosorb 102 Section

The analysis is identical to that described for the above, except the thermal desorber block temperature is 150° C.

Preparation of Standards

Depending on the findings of the sample analysis, standards may be run to confirm identifications and to quantify the materials found. Due to the small quantities required (0.1 to 1.0 μ), the material(s) of interest must be handled in solutions. The solvent used to prepare the standards must be selected with care to ensure that it does not interfere with the GC-MS determination. Prior to injecting an aliquot of the standard solution into a glass wool plug, the 8 mm O.D., 11 cm long tube holding the glass wool is chilled (frosted) over liquid nitrogen to minimize evaporation of volatile components while the Swagelok connections are being made.

As an alternative to the chilling, a septum on the helium inlet fitting may be constructed to permit injection of the standard after the Swagelok connections have been made.

CONCLUSIONS

If the two-stage tube continues to live up to the evaluation study, it appears that the USEPA will be able to collect fewer air samples, receive better turnaround time and obtain a sufficient identification of many of the low-level organic air contaminants. With this information, the USEPA will be better able to identify and develop a site-specific air monitoring program.

ACKNOWLEDGEMENT

FIELD SAMPLING FOR MONITORING, MIGRATION AND DEFINING THE AREAL EXTENT OF CHEMICAL CONTAMINATION

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INTRODUCTION

As part of two studies funded by the U.S. Nuclear Regulatory Commission and the USEPA, the authors have investigated field sampling strategies and compositing as a means of detecting spills or migration at commercial low-level radioactive and chemical waste disposal sites and bioassays for detecting contamination at chemical waste sites.

Compositing (pooling samples) for detection[1] is discussed first, followed by the development of a statistical test to determine whether any component of a composite exceeds a prescribed maximum acceptable level.[2] Subsequently, the authors explore the question of optimal field sampling designs[2] and present the features of a microcomputer program designed to show the difficulties in constructing efficient field designs and using compositing schemes.[3] Finally, they propose the use of bioassays as an adjunct or replacement for chemical analysis as a means of detecting and defining the areal extent of chemical migration.

COMPOSITING

A working definition of a composite sample obtained from commercial radioactive low-level or chemical waste sites (CLLCW) might be the mass of air, water, biota or soils resulting from pooling several individual samples together before radioanalysis is done. Compositing samples from CLLCW sites will become attractive when the cost of a single analysis is large relative to costs of collecting, pooling and adequately mixing samples.

One purpose of compositing is to obtain an estimate of average concentration of a radionuclide or chemical in some biotic or abiotic component which might move off-site.[4] In contrast, another purpose might be detection of on-site spills, areas of unacceptably high radioactivity or possible radionuclide migration during routine site operation.[4] The desired outcome in the first case is an estimate of concentration and an appropriate estimate of variance. When compositing for detection, the desired outcome is a statement of the probability that none of the samples making up the composite contained more than some amount (e.g., 1 nCi/g or ppm) and a confidence limit for the probability estimate.

Several papers which deal with compositing for detection have been previously reviewed.[1, 2] Some possible scenarios for detecting spills at CLLCW sites are illustrated in Figure 1. All 16 soil samples are composited (mixed) in scenario 1, random selection of four samples from the entire site make up each composite depicted in scenario 2, while in scenario 3 the compositing is done within four

selected site locations (A through D, possibly based on some prior knowledge). In all these scenarios a subsample is used for analysis.

The apparent spills or hot spots are shown as the open circles in the figure. For purposes of illustration, it is assumed that when one hot spot is composited with three background samples, the resulting contamination cannot be detected in the subsequent analysis.

In scenario 1, detection of spills would actually depend on the level of contamination, the dilution by 12 background soil samples, the ability to mix 16 samples uniformly and the subsample size (when aliquots are analyzed). Under the assumption above, the contamination in the scenario 1 sample would go undetected. A spill probably would be detected under scenario 2 (unless only one hot sample happened to be selected in each of the four composites), but the location would have to be determined by an additional analysis of the four individual components (perhaps only half of each of the original four samples was used to form the composite). Site B would be identified as contaminated under scenario 3, but Site C could be missed. Many other possible scenarios could be constructed. Thus, a generalized and statistically based strategy for compositing is evidently needed.
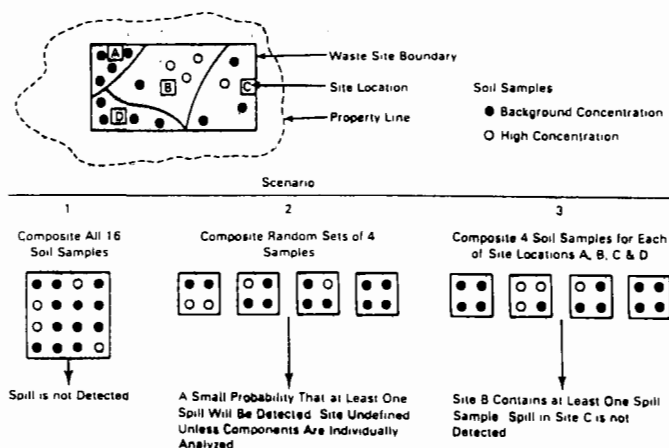
Figure 1
Hypothetical Example of Compositing to Define Spills at a Hypothetical Waste Site. To interpret the analytic results, assume that one soil component (high concentration) mixed with three background soil samples is not detectable by the analytic technique employed.

DETECTING A MAXIMUM ACCEPTABLE LEVEL

Compositing samples can result in appreciable cost reduction when chemical or radiochemical analyses are expensive.[5] However, the loss of information due to grouping samples and the subsequent averaging of contaminant levels needs to be minimized (e.g., compositing samples can result in conta.....iant dilution where it is not detected).

Excessive contaminant dilution can be minimized by specifying a minimum detection limit for the analytic procedure (MDL) and a maximum acceptable level of contamination within the substrate (MAL). Under these constraints, the maximum number of samples that can be grouped into a single composite is:

$$n \leq \frac{MAL}{MDL} \qquad (1)$$

provided that perfect mixing can be assumed or large masses of material can be analyzed.

By limiting the size of a composite to n components, a sample just at the MAL will still be above detection limits if mixed with (n - 1) samples with very low concentrations. The following three analytic outcomes may occur in the analysis of a composited sample (Fig. 2):
- Observed concentration is below detection limits so we conclude all n components are below MAL.
- Observed concentration is between MDL and MAL, indicating the possibility that one or more components may be above the MAL.
- Observed concentration is above MAL, indicating that one or more components are contaminated at a concentration above MAL.

In the first case above, a null hypothesis of no contaminated samples can be accepted with probability 1, while in the last case a null hypothesis of no excessive contamination can be rejected with probability 1. However, the intermediate condition (second case) requires further evaluation to determine whether there is a high probability of components which contain excessive contamination.

When the parameters for the distribution of background concentration (i.e., mean and variance) are known, a statistical test for group testing can be performed based on the observed composite concentration. This group testing procedure is most applicable when chemical analyses are expensive, frequency of contamination is low, contamination levels are well above background, uncertainties of field sampling are great and numerous samples are collected. The significance level of the group test can be interpreted as the probability of declaring that one or more of the n components in a composite exceeds the MAL when in fact they do not. Composited samples with significance levels below 5%, or some other cutoff point, would be candidates for further laboratory analysis of individual components (assuming some of each was saved) to determine which components were actually contaminated.

Safety of n Components in a Composite

All Are Safe	One or More May Be Unsafe	One or More is Unsafe
Probability = 1	Compute Probability	Probability 1

Analytic Concentration in the Composited Sample
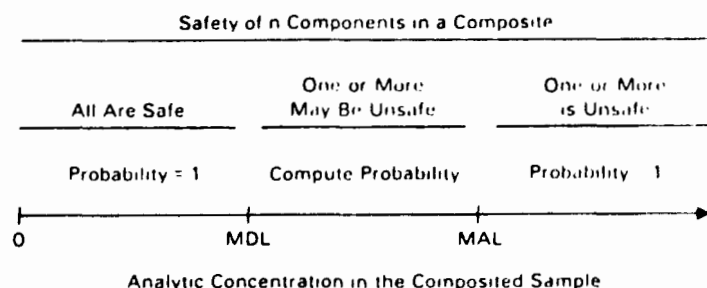
Figure 2
Concentrations of a Chemical or Radiochemical in a Composited Sample Made Up of n Component Subsamples. The conclusion regarding safety depends on whether the composite level exceeds the minimum detection limit (MDL) or the maximum acceptable level (MAL) for the contaminant.

A test statistic has been developed[2] and preliminary tables (obtained by computer simulation) have been prepared. Current work is focused on either obtaining an analytic solution (or an adequate approximation to the solution) of the equations which would allow a complete set of tables to be constructed. Currently, tables depend on a five point entry consisting of the critical value for the mean concentration of n-composited samples from a background distribution with an estimated mean and variance, observed average concentration for a particular composited sample, the nth order statistic for a sample of size n (i.e., the highest concentration among the components in the composited sample), maximum acceptable level or concentration (i.e., possible values for MAL) and the significance level of the test (type 1 error, often 5%).

The joint probability can be interpreted as the intersection of events when a mean composite concentration equals or exceeds the background critical level and all n individual components have concentrations less than or equal to the maximum acceptable level. Thus, the probability of falsely rejecting the null hypothesis (all components in the composite are below the MAL) can be found using tables of the test statistic.

The results of limited simulations show that the test is highly effective with large sample sizes (many components in a composite, again assuming perfect mixing or the ability to analyze large samples) where contaminant levels frequently exceed the MAL. These conditions of frequent and high contamination levels are likely to occur in regions of a commercial waste site where the prior knowledge (priors) for a spill or migration are highest.

FIELD SAMPLING BASED ON PRIOR INFORMATION

Historical records on land use or cursory surveys of waste sites often suggest possible locations where a search for spills can begin. This *a priori* information can improve the success rate of a survey scheme. However, in the absence of prior knowledge, more general strategies for sampling are needed.

The most general approach is systematic (uniform) sampling based on grid systems or lattice designs.[4] Recently, it has been suggested that the grid should be triangular for a fixed area because fewer samples may be required (unless systematic dumping is suspected).[5] Nomograms for square, rectangular and triangular grids which can be used to select sample spacing for circular and elliptical spills have also been developed.[6] In this study, the authors investigated how prior knowledge [prior(s) is standard terminology in Bayesian statistics] might be used to devise alternative sampling designs.

A Bayes sampling approach can be defined as a sampling strategy chosen from a series of alternative schemes which best minimizes the risk of missing a spill. To illustrate the concept, competing sampling designs for a specific spill scenario were evaluated. The situation selected is one where the location of a surface soil spill is known, but because of uncertainty about the mechanism by which the contaminant has spread, the extent of contamination over the waste site is unknown. Therefore, the initial objective of the sampling program is to determine the size of the spill zone.

Three prospective contaminated zones within the waste site are identified in Figure 3. Zone A, an area centered around the suspected spill site, has a high probability of encompassing part of the spill. The second zone (zone B) is concentric about zone A and has a slightly higher probability of containing the spill since it encompasses zone A. This second area (zone B) is considered a margin of safety in case zone A does not encompass the spill. The third zone (C) is the remainder of the site and supposedly has very little chance of contamination. The actual spill shown in Figure 3 indicates that the initial suppositions were not entirely correct.

The following three alternative contamination scenarios are possible:
- Contamination is confined within zone A, 9% of the site area
- Part of the contamination has migrated beyond zone A but is confined within zone B, 8% of the site area and site A.

• Some contamination is in zones A, B and C (zone C contains 83% of the site area).

Only one scenario can exist during the sampling period. The objective is to choose between the three scenarios.
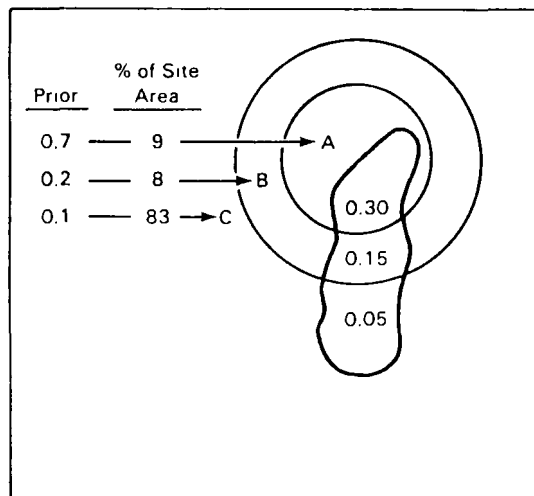
Figure 3
Hypothetical Dispersion of a Contaminant Through Three Sampling Zones, A, B and C. The size and configuration of the zones are based on prior information and may be best guesses. In this case, the guesses were not entirely correct. The unlabeled decimal values are the areal proportion of the plume included in each zone.

A probability has been arbitrarily assigned to each scenario. Those probabilities, called priors, were arbitrarily set at 0.70, 0.20 and 0.10 (the probability that the contamination is in zones A, B and C, respectively). Together, these probabilities are mutually exclusive and their sum is one.

Different sampling strategies at the hypothetical waste site were evaluated based on their performance under each alternative scenario. Of the alternative sampling strategies possible, only those which allocate sampling efforts based on areal zone size and/or the priors for the chances of contamination were considered. Using these two criteria, the following five possible strategies were defined:

Sampling Strategy	Description
S_1	Allocation proportional to area
S_2	Allocation proportional to area and prior
S_3	Allocation proportional to area and inversely proportional to prior
S_4	Allocation proportional to prior
S_5	Allocation inversely proportional to prior

Using these basic data and a risk function (computed by subtracting the minimum loss among sampling strategies within scenarios, where loss is the probability of missing the contamination in any zone),[2] each sampling strategy was ranked for three possible scenarios: 30% of zone A was contamined; 30% of zone A and 15% of zone B were contaminated; and 30% of zone A, 15% of zone B and 5% of zone C were contaminated (Fig. 3).

These scenarios correspond to one set of beliefs as to where and how far the spill could have migrated. The computed weighted risk functions in Table 1 indicate that the strategy with minimum risk results when samples are allocated as the reciprocal of the prior probability (S_5). Two other strategies (S_2, S_4) had slightly higher weighted risk, while the strategy based on area/prior (S_3) resulted

in the highest risk. Actual field sampling allocation, given 100 samples, under the five strategies would be very different (Table 2). None of the strategies would result in an equal distribution of sampling effort over the site.

Finally, the authors note that the work on compositing indicates there should be more intensive sampling in suspected high concentration areas (high priors), while work on optimum designs yields the opposite result (that is, fewer samples in areas where priors for the spill are highest). This indicates that an optimum strategy may exist and future research should be directed to obtaining such results.

Table 1
Calculated Weighted Risk for Five Sampling Strategies and Three Scenarios for the Example Spill in Figure 1
(See reference 2 for detailed calculations.)

Contamination Scenario		Risk and Weighted Risk for Each Sampling Strategy (S_1)				
	Prior	S_1 Area	S_2 Area x Prior	S_3 Area/Prior	S_4 Prior	S_5 1/Prior
30% Zone A	0.7	0.04	0	0.70	0	0.04
30% Zone A, 15% Zone B	0.2	0.26	0.16	0.79	0	0.01
30% Zone A, 15% Zone B, 5% Zone C	0.1	0.22	0.14	0.75	0.52	0
Weighted Risk		0.10	0.05	0.72	0.05	0.03

Table 2
Calculated sample allocations for five sampling strategies as a function of the percentage of the total site area represented by each zone and priors (0.7, 0.2 and 0.1 for zones A, B and C, respectively). One hundred samples were allocated for each strategy. (See reference 2 for detailed calculations.)

Zone	Percent	Sample Allocation Based on Each Strategy				
		Area	Area x Prior	Area/Prior	Prior	1/Prior
A	9	9	39	1	70	9
B	8	8	10	5	20	30
C	83	83	51	94	10	61
Sum	100	100	100	100	100	100

DIGMAN—A MICROCOMPUTER PROGRAM

DIGMAN[3] was developed for site managers to illustrate the difficulties in sampling commercial radioactive low-level waste sites and to allow cleanup personnel to evaluate alternative sampling strategies. This interactive program tests one's ability to locate a contaminated area and to determine its areal extent. The actual field sampling design and the decision to use compositing are under program user control.

In the DIGMAN scenario, it is assumed that historical records or a preliminary site survey indicate that contamination is present and that the highest possible concentration is ten units per area. By sampling the site soils, the extent of contamination must be determined and a decision made as to whether or not the contaminant has migrated off-site. Because of high laboratory costs, only five samples (which can be composites) can be analyzed. Each of the five permitted composite samples can be composed of from one to nine component samples (e.g., up to nine samples can be com-

bined into one sample), but only the total sample may be analyzed. Even though sampling is restricted to the waste site, the contaminated area may extend beyond site boundaries. After sampling, the site manager must determine the areal extent of the contamination. Since site cleanup costs are assumed to be very high, the smallest possible estimate of the contaminated area is desirable to avoid condemning a larger area than necessary.

Several different scenarios related to sampling and costs can be used. For instance, costs of collecting and analyzing samples may be high so the site manager would probably obtain the maximum number of components per composite as well as all five composite samples. In another case, collection costs may be low but analyses still expensive. Thus, the site manager might take fewer than five composite samples, analyze the results and resample. The case where collecting samples is expensive, while analyses are relatively cheap, would again result in selecting maximum numbers of components and composites. When costs of collection and analyses are inexpensive, compositing is not advantageous.

DIGMAN also allows the site manager to resample after the first sampling sequence is completed and the analytical results are available. This two or more stage sampling is analogous to the circumstances where laboratory turnaround is fast (and perhaps cheaper than assumed in DIGMAN) and should allow a better definition of the spill area.

The waste site is simulated as a 40 x 40 grid. The site manager is given information that contamination exists at least at one point on the waste site (this appears on the screen as a darkened square and is called a prior). However, the concentration at this point is not known since in real circumstances a site manager will usually only have sketchy information.

The contaminated area is represented by an ellipse, because point spills are generally moved by physical forces (e.g., wind or surface water). The ellipse is generated using a bivariate normal distribution, and parameters affecting placement, orientation and shape are randomly determined. Thus, the ellipse can be very small or large and of varying length and width (e.g., very "skinny" or "fat"). In addition, it is possible for part of the ellipse to be outside the defined waste site, an indication that contamination has moved off-site.

Sampling success is evaluated based on the following three criteria:
- The proportion of the contaminated area (ellipse) within a user supplied circle. The site manager supplies the radius and the estimated center of contamination.
- The fraction of the user chosen radius compared to the longest radius of the ellipse (which indicates whether the manager was conservative in estimating the size of the contaminated area).
- The accuracy of the prediction that contamination was restricted to the site.

MAPPING CHEMICAL CONTAMINATION USING A PHYTOASSAY

In order to demonstrate the usefulness of bioassays in chemical hazard assessment, a field study was conducted at Rocky Mountain Arsenal (RMA) in Commerce City, Colorado. Only the results from photoassays of site soils are presented here; results of other bioassays are in the article by Thomas et al.[10]

The site had been used for the manufacture of anti-personnel gases, herbicides, insecticides and as an ordinance testing area. Over the years, a myriad of organic and inorganic compounds were carried through ditches to a series of interconnecting holding basins for disposal. Thus, site soils would be very expensive to completely specify chemically and offered an excellent phytoassay opportunity.

Study Site

Four parallel transects were established near a waste trench, each beginning on the north bank of the trench and running south for approximately 90 m. A logarithmic sampling scale was used beyond

the south trench edge to locate sampling points, because contamination probably moved by some physical means (e.g., wind or water). The transects were 15 m apart. The first three sample points of each transect fell within the trench and the fourth was on the top of the south bank. Sample numbers 5 through 9 were 15, 20, 30, 50 and 90 m, respectively, south of the north trench edge.

Soil Sampling

At most sampling points, a split spoon corer mounted on a hydraulic drill rig was used to take two soil cores, one from a depth of 0 to 15 cm, and a second from 15 to 30 cm. Each core was 7.6 cm in diameter and together they weighed approximately 4 kg. Between sampling points, the split spoon and drill bit were decontaminated by washing with methanol and rinsing with distilled water. All samples were placed in plastic bags, sealed and labeled. The area being sampled and any problems encountered (e.g., mud, accessibility) dictated exactly how the cores were taken and any variations on the basic sampling scheme.[9] The lettuce seed phytoassay used is described by Thomas and Cline.[11]

Photoassay Results

Two seed mortality experiments (0-15 cm and 15-30 cm soil samples respectively) were conducted and the maximum mortality difference between those soils assayed in both experiments was about 15%. Using this value as a cutoff point to assess mortality differences at the two depths showed (on inspection) that lettuce seed mortality differed (the 15-30 cm soil samples caused higher lettuce seed mortality). Moreover, seven samples exhibited much higher mortality at the 15-30 cm depth compared to their 0-15 cm fractions, suggesting that the contaminants had either migrated below 15 cm or were purposely placed there.

Mapping Chemical Contamination

One way to depict lettuce seed mortality patterns at each depth was to prepare a contour map based on the observations. The authors elected to use a relatively new statistical technique called kriging developed for use in the mining industry and used principally in Europe and South Africa[12,13] to calculate map contours.

Kriging is a weighted moving average technique that calculates point estimates or block averages over a specified grid. The derivation of the kriging weights takes into account the proximity of an observation to the point or area of interest, the structure of the observations (i.e., the relationship of the squared difference between pairs of observations and the intervening distance between them) and any systematic trend or drift in the observations. Additionally, kriging provides a variance estimate that can be used to construct a confidence interval for the estimated observations. Contour maps are prepared from the kriging estimates.

The results of kriging the 0-15 cm lettuce seed mortality are shown in Figure 4. The contamination predicted by kriging was greater at 15-30 cm compared to 0-15 cm, confirming the preliminary analysis based on the observed data.

Maps similar to Figure 4 could be useful in site cleanup decisions (especially when accompanied by error estimates). As a possible scenario, if the 30% mortality contour was elected as a criterion for cleanup of the trench site, the area in Figure 4 enclosed by the solid line would be targeted for cleanup. Unfortunately, the cleanup decision would be different for the 0-15 cm and the 15-30 cm soil fractions. While this would complicate decision making, it is the field situation that is complex, so decisions based on the 0-15 cm samples alone could have unwanted consequences. In the current case, samples below 30 cm would be needed to make a defensible decision.

CONCLUSIONS

This paper summarized initial research on compositing, field designs and site mapping oriented toward detecting spills and migration at commercial low-level radioactive or chemical waste sites.
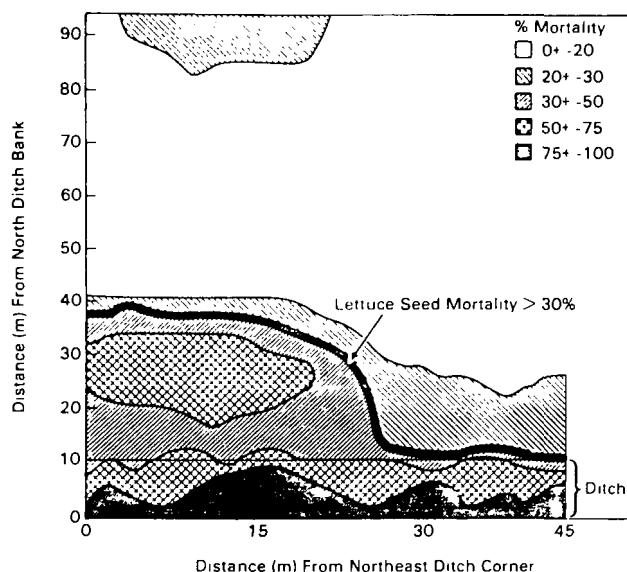
Figure 4
Predicted Lettuce Seed Mortality Using Kriging. The observed data
were obtained using 0-15 cm soil cores from the Rocky
Mountain Arsenal.

arithmic sampling sites (about 4000 m²) at two depths (0-15 cm and 15-30 cm), mortality maps were obtained using kriging techniques. Predicted mortality (as well as observed mortality) was greater at the 15-30 cm depth. The results indicate that phytoassay, accompanied by kriging, can aid in site cleanup decisions and in defining the extent of contamination, particularly if the estimated contours are accompanied by kriging errors.

ACKNOWLEDGEMENTS

Results indicate that the significance test developed to detect samples containing high levels of contamination when they are mixed with several other samples below detectable limits (composites) will be highly effective with large sample sizes when contaminant levels frequently or greatly exceed a maximum acceptable level. These conditions of frequent and high contaminant levels are most likely to occur in regiờ:s of a commercial waste site where the priors (previous knowledge) about a spill or migration are highest. Conversely, initial investigations of Bayes sampling strategies suggest that field sampling efforts should be inversely proportional to the priors (expressed as probabilities) for the occurrence of contamination. In other words, fewer samples should be allocated at the probable source of a spill, with greater emphasis placed on confirming the absence of contamination in suspected "clean" areas.

Together, the joint results on group testing and sampling designs suggest that fewer but larger composite samples should be collected at the suspected source of a spill, while smaller and more frequent composite samples should be taken in areas where uncertainty is greatest. By using this approach, the effectiveness of group testing is maintained along with the efficiency of the Bayes strategies in allocating field sampling effort. It is this prospect for coordinating the laboratory compositing and field sampling schemes which holds the greatest promise for efficient and cost-effective detection of spills and defining migration.

The DIGMAN microcomputer program was developed to illustrate the complexities in sampling waste sites for spills or migration. The site-manager is given prior knowledge that a spill has occurred and that it has subsequently migrated through or over the soil surface. In addition, the location is given for one point where some contamination is known to exist. Such an array of information may or may not be available at actual sites. The DIGMAN waste site provides 1600 possible sampling sites, clearly far fewer than would be available at an actual waste site. Thus, the situations depicted by DIGMAN are perhaps the simplest of the myriad of possible scenarios that might be faced by a site-manager. A floppy disc copy of the program can be obtained from the authors.

In order to illustrate how phytoassay results could be used to map the toxic potential of a chemical waste site, a small scale field study was conducted at the Rocky Mountain Arsenal. Based on the results from lettuce seed phytoassays of soil samples from 36 log-

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SUBSAMPLING OF HAZARDOUS WASTE

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INTRODUCTION

The California Department of Health Services (DOHS) protocol[1] for assessment of hazardous waste requires that representative samples be first analyzed for total concentrations of chemicals. When testing for toxicity, if the 80% confidence limit of the total concentration obtained from the sample analytical data exceeds the total threshold limit concentration (TTLC), then the material analyzed is considered hazardous waste. If the 80% confidence limit is below the soluble threshold limit concentration (STLC), then the material is not considered hazardous.

However, when the 80% limit is above the STLC and below the TTLC, then a subsample must be analyzed using the California Waste Extraction Test (CWET), and a new 80% confidence limit must be calculated based on the results of the CWET analyses. If this new limit is higher than STLC, then the conclusion can be made that the waste is hazardous.

A Avenue

Sample locations

Figure 1
Soil Sampling Locations on the Site Investigated for Site Assessment

In this paper, the authors discuss the selection of subsamples for CWET analyses as well as the statistical analysis of data for site assessment in California. The data utilized in this paper are adapted from an actual site assessment project, but the particular site and other project details have not been identified because of a confidentiality agreement.

SITE DESCRIPTION AND SAMPLING PROGRAM

The study site is a 40-acre tract in California (Figure 1) that has been used for ranching, farming and oil production since 1920. A few oil wells are still operating on the site. The current owner purchased the tract in 1983 and planned development of the land. The oily wastes at the site needed excavation to assess whether or not they were hazardous.

Sample locations (Figure 1) were randomly selected in areas where oil wells, storage tanks, sumps and/or pipelines were or had been present. There was no visible surface evidence of these locations because the area was covered by vegetation.

The site assessment program consisted of the following tasks: review of available site data, interpretation of the historic aerial photographs, preparation of field program to collect soil samples from assigned locations, chemical analysis of soil samples and statistical analysis of the data. The soil samples were analyzed for several chemical constituents. For the purposes of this paper, the authors limited their discussion to eight heavy metals: arsenic, copper, chromium, nickel, lead, vanadium, zinc, barium and cadmium.

CHEMICAL ANALYSIS DATA

Following the DOHS protocol, 24 soil samples were chemically analyzed for the total concentrations of the eight heavy metals. The chemical analysis results are shown in Table 1. The table shows the sample locations, the heavy metal total concentration in the soil samples from these locations and the total and soluble threshold limit concentrations (TTLC, STLC) for these metals as published by DOHS.[1] Since the authors' objective was to discuss the subsampling, only barium concentrations were selected for detailed discussion. The subsampling and the associated statistical analysis procedure developed for barium was applicable to the chemical concentrations of all the other heavy metals on the site.

The barium concentration in the 24 samples ranged from 34.6 to 538.0 ppm. In spite of such a large range of concentrations, most of the values were close to 100 ppm. The frequency polygon and the cumulative frequency polygon for these data are shown in Figure 2. All the values are below the barium TTLC value of 10,000 ppm,
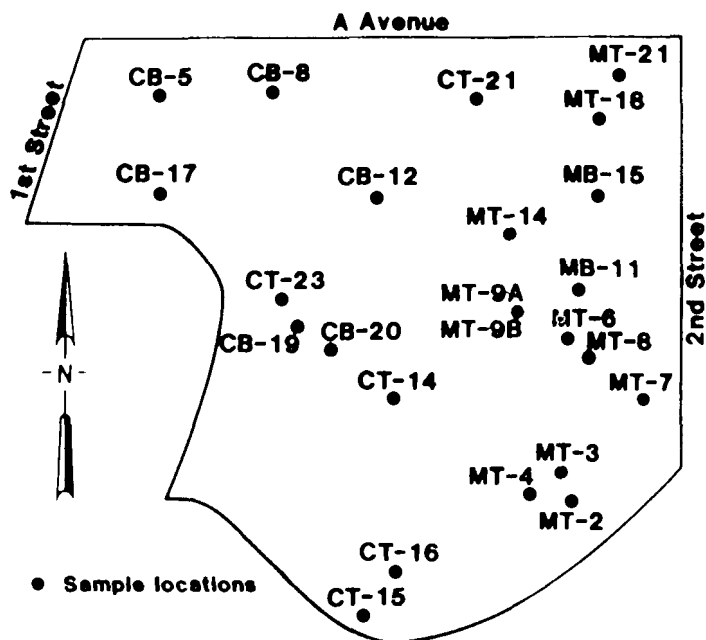
Table 1
Total Concentrations of Selected Heavy Metals in Waste Material

Sample Location	As	Cu	Cr	Ni	Pb	V	Zn	Ba	Cd
				Heavy Metals (mg/kg = ppm)					
CB-5	40.2	7.6	17.2	12.1	5.2	41.1	45.8	58.8	<0.05
CB-8	30.2	13.1	20.3	13.3	4.8	37.2	43.9	76.8	<0.05
CB-12	36.2	7.9	16.9	13.9	5.6	39.3	43.1	67.5	<0.05
CB-14	41.7	15.0	22.6	24.7	82.5	44.0	62.6	131.0	0.19
CB-15	24.6	10.4	16.6	12.8	10.3	34.1	45.6	74.5	0.11
CB-16	34.1	16.8	31.9	16.6	6.9	40.2	39.2	86.6	<0.05
CB-17	29.2	6.7	15.5	10.5	4.8	31.5	36.0	34.6	<0.05
CB-19	26.4	7.7	15.0	9.3	5.7	28.6	53.1	37.4	0.05
CB-20	26.0	56.1	13.5	11.9	10.7	31.1	90.7	53.6	<0.05
CB-23	29.3	8.8	25.2	13.6	4.1	30.3	30.8	63.1	0.09
CB-21	16.9	12.2	14.6	12.8	45.8	29.0	43.2	76.6	0.50
MT-2	42.8	12.6	23.7	15.5	5.0	47.4	46.4	113.0	0.08
MT-3	4.6	13.3	21.8	15.0	0.5	47.5	49.2	93.8	0.03
MT-4	2.1	22.2	22.5	30.4	0.76	39.6	104.0	102.0	0.02
MT-6	24.0	10.7	15.2	12.6	5.3	32.1	31.0	95.5	0.10
MT-7	23.7	16.7	19.9	15.5	14.8	36.0	52.4	102.0	0.09
MT-8	44.1	50.7	27.3	28.0	49.3	47.7	426.0	114.0	<0.05
MT-9A	3.2	17.9	47.8	17.6	2.2	31.7	112.0	148.0	0.04
MT-9B	22.7	11.5	15.8	9.7	14.8	32.5	35.1	68.5	0.03
MT-14	14.7	14.4	14.5	14.1	28.4	27.2	39.1	87.8	0.10
MB-11	2.2	11.8	14.3	12.2	<0.5	31.9	44.0	80.3	0.10
MB-15	35.9	13.6	19.3	14.3	3.0	39.3	44.3	195.0	<0.05
MT-18	3.5	31.9	21.7	27.5	2.2	49.9	131.0	538.0	0.11
MT-21	19.4	14.9	14.5	14.5	15.5	29.9	52.1	307.0	0.02
TTLC	500	2,500	2,500	2,000	1,000	2,400	5,000	10,000	10
STLC	5	25	560	20	5	24	250	100	1

but there are a few sample values which exceed the barium STLC value of 100 ppm. Thus, the 80% confidence level of barium concentrations is likely to be between 100 and 10,000 ppm.

By the DOHS protocol, CWET test results for soluble barium concentration in the soils were required to assess if the material constituted a hazardous waste. Thus, a subsampling of sample population was needed to make such an assessment.

FREQUENCY POLYGON OF Ba CONCENTRATION

FREQ
(# of Samples)

X - Total Barium Concentration (ppm)

CUMULATIVE FREQUENCY POLYGON OF Ba CONCENTRATION

CUM. FREQ

X - Total Barium Concentration (ppm)
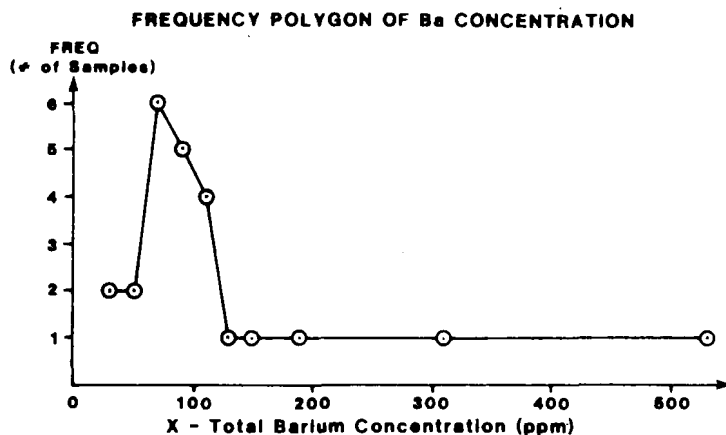
Figure 2
Observed Polygons of Barium Concentration

STATISTICAL RESULTS USED IN SUBSAMPLING

The first statistical analysis was performed on the distribution of the total barium concentration. The data shown in Table 1 and plotted in Figure 2 indicate that the distribution is highly peaked around 100 ppm, skewed and long-tailed toward higher concentration values. Such a distribution can hardly be assumed to represent a symmetric normal distribution.[2] Therefore, the mean value of 116.9 ppm and the standard deviation of 106.0 ppm shown in Table 2 could not be satisfactorily used to calculate upper 80%. It was therefore necessary to evaluate a data transformation which could approximately normalize the barium data distribution and help calculate an 80% confidence value for the hazardous waste classification.

Three transformations were evaluated. Assuming that T represented total barium concentration in samples, the transformations were as follows:

$$X = \operatorname{Sin}^{-1} \sqrt{T/10^6} \qquad (1)$$
$$Y = \ln(T) \qquad (2)$$
$$Z = \sqrt{T} \qquad (3)$$

Table 2
Transformed Values of Total Barium Concentration in Waste Materials

Sample Location	T-Total Barium Concentration (ppm)	$X = \operatorname{Sin}^{-1}\sqrt{T/10^6}$	$Y = \ln(T)$	$Z = \sqrt{T}$
CB-5	58.8	0.4394	4.0741	7.6681
CB-8	76.8	0.5021	4.3412	8.7636
CB-12	67.5	0.4707	4.2121	8.2158
CT-14	131.0	0.6558	4.8752	11.4455
CT-15	74.5	0.4945	4.3108	8.6313
CT-16	86.6	0.5332	4.4613	9.3059
CB-17	34.6	0.3370	3.5439	5.8822
CB-19	37.4	0.3504	3.6217	6.1156
CB-20	53.6	0.4195	3.9815	7.3212
CT-23	63.1	0.4551	4.1447	7.9436
CT-21	76.6	0.5015	4.3386	8.7521
MT-2	113.0	0.6091	4.7274	10.6301
MT-3	93.8	0.5549	4.5412	9.6850
MT-4	102.0	0.5787	4.6250	10.0995
MT-6	95.5	0.5599	4.5591	9.7724
MT-7	102.0	0.5787	4.6250	10.0995
MT-8	114.0	0.6118	4.7362	10.6771
MT-9A	148.0	0.6971	4.9972	12.1655
MT-9B	68.5	0.4742	4.2268	8.2765
MT-14	87.8	0.5369	4.4751	9.3702
MB-11	80.3	0.5134	4.3858	8.9610
MB-15	195.0	0.8001	5.2730	13.9642
MT-18	538.0	0.3291	6.2879	23.1948
MT-21	307.0	0.0040	5.7268	17.5214
Mean	116.9	0.5836	4.5455	20.2274
Standard Deviation	106.0	0.2122	0.6008	3.6900

X is appropriate if T is binomial, Y if T is lognormal and Z if T is a poisson variable.[3] The transformed total barium concentration values, their means and standard deviations are shown in Table 2. To evaluate which of these transformations was suitable, all of the data shown in Table 2 were standardized by subtracting the mean from each value and dividing the difference by the standard deviation. These standardized values (T_1, X_1 and Z_1) are shown in Table 3.

The observed distribution of each of the standardized variate against standard normal distribution (mean = 0, standard deviation = 1) was tested by the chi-square goodness of fit test.[3] The chi-square values and associated results are graphically shown in Figure 3. The probability of the chi-square exceeding 12.75 at 6 degrees of freedom is less than 0.0472; among the three distributions, Y = ln(t) was considered closest to the normal distribution. Thus, Y = ln(t) values were used in the decision-making calculations.

The second statistical analysis concerned the proportion of the samples whose observed T value exceeded the barium STLC value of 100 ppm. In terms of Y = ln(t), it referred to the number of samples whose values exceeded ln (100) = 4.6052. The samples exceeding this threshold value were included in Group 1, and those not exceeding the threshold value were included in Group 2. These data with their means and standard deviations are shown in Table 4.

Table 3
Standardized Values T_1, X_1 and Z_1 of Barium Concentrations in Waste Materials Obtained by Subtracting the Mean and Dividing by the Standard Deviation of Table 2

Sample Location	T_1	X_1	Y_1	Z_1
CB-15	-0.5481	-0.6795	-0.7846	-0.6936
CB-8	-0.3783	-0.3841	-0.3400	-0.3967
CB-12	-0.4660	-0.5320	-0.5549	-0.5451
CT-14	0.1330	0.3402	0.5488	0.3301
CT-15	-0.4000	-0.4195	-0.3906	-0.4325
CT-16	-0.2858	-0.2375	-0.1401	-0.2497
CB-17	-0.7764	-0.1621	-1.6671	-1.1776
CB-19	-0.7500	-0.0990	-1.5376	-1.1143
CB-20	-0.5972	-0.7730	-0.9387	-0.7876
CT-23	-0.5075	-0.6056	-0.6671	-0.6189
CT-21	-0.3802	-0.3869	-0.3444	-0.3998
MT-2	-0.0368	0.1202	0.3028	0.1091
MT-3	-0.2179	-0.1352	-0.0072	-0.1470
MT-4	-0.1406	-0.0231	0.1323	-0.0347
MT-6	-0.2019	-0.1117	0.0226	-0.1233
MT-7	-0.1406	-0.0231	0.1323	-0.0347
MT-8	-0.0274	0.1329	0.3174	0.1219
MT-9A	0.2934	0.5349	0.7518	0.5252
MT-9B	-0.4566	-0.5156	-0.5305	-0.5287
MT-14	-0.2745	-0.2201	-0.1172	-0.2323
MB-11	-0.3453	-0.3308	-0.2658	-0.3432
MB-15	0.7368	0.0203	1.2109	1.0127
MT-18	3.9726	0.5132	2.9001	3.5142
MT-21	1.7934	0.9811	1.9662	1.9767

Table 4
Total Barium Concentration T and Y = 1n(T) of Samples and Their Group Classification

Sample Location	T-Total Barium Concentration (ppm)	Y = ln(T)	[Y > 4.6052] or [T > 100(STLC)] Group 1	[Y < 4.6052] or [T < 100(STLC)] Group 2
CB-5	58.8	4.0741	--	4.0741
CB-8	76.8	4.3412	--	4.3412
CB-12	67.5	4.2121	--	4.2121
CT-14	131.0	4.8752	4.8752	--
CT-15	74.5	4.3108	--	4.3108
CT-16	86.6	4.4613	--	4.4613
CB-17	34.6	3.5439	--	3.5439
CB-19	37.4	3.6217	--	3.6217
CB-20	53.6	3.9815	--	3.9815
CT-23	63.1	4.1447	--	4.1447
CT-21	76.6	4.3386	--	4.3386
MT-2	113.0	4.7274	4.7274	--
MT-3	93.8	4.5412	--	4.5412
MT-4	102.0	4.6250	4.6250	--
MT-6	95.5	4.5591	--	4.5591
MT-7	102.0	4.6250	4.6250	--
MT-8	114.0	4.7362	4.7362	--
MT-9A	148.0	4.9972	4.9972	--
MT-9B	68.5	4.2268	--	4.2268
MT-14	87.8	4.4751	--	4.4751
MB-11	80.3	4.3858	--	4.3858
MB-15	195.0	5.2730	5.2730	--
MT-18	538.0	6.2879	6.2879	--
MT-21	307.0	5.7268	5.7268	--
Number of Samples	24		9	15
Mean		4.5455	5.0971	4.2145
Standard Deviation		0.6008	0.5720	0.3053

Standardized Variable (Transformation)	Chi-Square
T (Observed)	29.67
X (sin $\sqrt{T \cdot 10^4}$)	12.75
Y (ln T)	5.17
Z ($\sqrt{T}$)	12.75

-1.0674 -0.5656 -0.1797 0 0.1797 0.5656 1.0674

Figure 3
Distribution Functions of the Standardized Variables

These two statistical results, (1) 1n(T) was approximately normally distributed and (2) a fixed STLC value partitioned the sample population into two mutually exclusive Groups 1 and 2, were utilized in the subsampling and in the site assessment.

SUBSAMPLING AND THE DECISION PROCEDURE

The subsampling procedure has been formalized in symbolic terms. The symbols have then been replaced by numbers using the statistical results of the previous section to make an assessment of material characteristics.

Suppose n representative samples are obtained from a site. Let T_1, T_2, ..., T_n be their total Barium concentrations. It is then assumed that $Y_1 = 1n(T_1)$, ..., $Y_n = 1n(T_n)$ are random samples from a normal distribution characterized by a mean and a standard deviation. The best statistical estimates of the mean and the standard deviation are $\overline{Y}$ and S_y computed from the formulae:

$$\overline{Y} = \Sigma Y_i/N \tag{4}$$

$$S_y^2 = \Sigma (Y_i - Y)^2/(n-1) \tag{5}$$

From $\overline{Y}$ and S_y values, the estimate of the average $T = \hat{T}$ and the upper 80% T value $= \hat{T}_{.80}$ are obtained by the following relations:

$$\hat{T} = \exp[\tilde{Y}] \tag{6}$$

$$\hat{T}_{.80} = [\overline{Y} + t S_y/\sqrt{n}] \tag{7}$$

where t is the 80% 't' value with (n – 1) degrees of freedom obtained from the statistical tables. Then, the conclusion that waste is hazardous or non-hazardous is made by the following two-step decision procedure.

Step 1.

If $\hat{T}_{.80}$ is greater than TTLC, then waste is hazardous.

If $\hat{T}_{.80}$ is smaller than STLC, then waste is non-hazardous.

If $\hat{T}_{.80}$ is in between STLC and TTLC, go to Step 2.

Step 2.

Perform CWET analysis for extractable barium in m samples out of a total of n samples (m is less than or equal to n). Let W_1, W_2, ... W_m be the extractable barium concentration values. Then compute appropriately an upper 80% confidence value $\hat{W}_{.80}$. If $\hat{W}_{.80}$ is greater than STLC, the waste is hazardous. If $\hat{W}_{.80}$ is less or equal to STLC, then the waste is not hazardous.

The procedure to select m samples out of a total of n samples at Step 2 addresses the subsampling problem. A subsampling and the related decision procedure is performed under the following guidelines.

a) Only m samples from the total n are to be selected for CWET analysis.

b) The proportion 'p' of T_i values exceed STLC. The r samples whose T_i exceed STLC belong to Group 1, and r = np . The remaining (n - r) samples with T_i less or equal to STLC belong to Group 2, and n – r = n (1 – p).

c) Select randomly mp samples from Group 1 and m (1 – p) from Group 2. Identify these m samples.

d) Perform CWET analysis and assume the extractable barium concentrations are W_1, W_2, ... W_m.

e) For these i = 1, 2, ... m samples, make transformations $V_i = 1n (W_i)$ and relable $Y_i = 1n (T_i)$ as U_i. Calculate the two means $\overline{U}$,

$\bar{V}$, the two standard deviations S_u, S_v and one correlation coefficient r between U_i and V_i.

f) Use the five statistics described in e above and the two Y statistics ($\bar{Y}$, S_y) to calculate $\hat{W}$ and $\hat{W}_{.80}$. If $\hat{W}_{.80}$ exceeds STLC, then it can be concluded that the waste is hazardous; otherwise, the waste is not hazardous.

The calculation of $\hat{W}$ and $\hat{W}_{.80}$ is performed by the following formulae.[4]

$$\hat{W} = \exp [V + r (S_v/S_u) (\bar{Y} - \bar{V})] = \exp [\tilde{V}] \qquad (8)$$

$$S\tilde{V}^2 = [S_v^2(1 - r)/m] [1 - (n - m)/(n(m - 3))]$$
$$+ r^2 S_y^2/n \qquad (9)$$

$$\hat{W}_{.80} = \exp [\tilde{V} + t S\tilde{V}] \qquad (10)$$

where t is the 80% 't' value at (m − 3) degrees of freedom obtained from the statistical tables.

The decision procedure described above has three important features. First, it utilizes the correlation coefficient between total and extractable barium concentrations. Second, it also accounts for the difference between the average of all the samples and the average of subsamples. Finally, it further balances the subsampling between the Groups 1 and 2 in relation to the population proportions of samples which exceed or do not exceed particular STLC value.

Since m subsamples are obtained by randomization, this procedure thus ensures that the estimates calculated from the data remain statistically unbiased. In contrast, a selection of all m subsamples from Group 1 alone or any subjective method is likely to add either a positive or a negative bias for hazardous waste classification.

CONCLUSIONS FOR THE SITE FROM SUBSAMPLING

The subsampling and the decision procedure presented symbolically in the previous section were used to make conclusions about the presence of hazardous waste on the site. There were n = 24 samples with locations as shown in Figure 1. The total barium concentrations (T) at these locations are given in Table 2. Project considerations stipulated that at most m = 10 samples could be subjected to CWET analysis. As shown in Table 4, there were 9 samples in Group 1 and 15 in Group 2. Thus, proportion 'p' was 9/24 = .375.

A random selection of 10 (.375) $\cong$ 4 samples from Group 1 and 10 − 4 = 6 samples from Group 2 was made to perform CWET analysis. These 10 random sample locations and the total (T) and soluble (W) concentrations of barium in the soil samples at these locations are shown in Table 5. Table 5 also contains data on the means, the standard deviations and the correlation between the transformed U and V values.

The positive correlation coefficient of 0.9362 indicated a very strong relationship between the total and soluble barium concentrations. This demonstrated that at this particular site the soluble barium concentration in the waste depended only on the total concentration and on no other factors related to waste constituents.

Table 5
Total and Soluble Barium Concentrations (ppm) in the 10 Subsamples Selected from a Total of 24 Samples of Waste Materials

Sample Location	Group	Total T	Soluble W	U = lnT	V = lnW
CB-8	2	76.8	42	4.3412	3.7377
CT-15	2	74.5	29	4.3108	3.3673
CB-17	2	34.6	16	4.5439	2.7726
CB-19	2	37.4	21	3.6217	3.0445
MT-6	2	95.5	62	4.5591	4.1271
MT-14	2	87.8	36	4.4751	3.5835
MT-8	1	114.0	56	4.7362	4.0254
MB-15	1	195.0	153	5.2730	5.0304
MT-18	1	538.0	162	6.2879	5.0876
MT-21	1	307.0	97	5.7268	4.5747

Number of Subsamples Group 1 = 6 $\bar{U}$ = 4.6876 $\bar{V}$ = 3.9351

Number of Subsamples Group 2 = 4 S_u = 0.8663 S_v = 0.7896

Total Number of Subsamples = 10   Correlation between (U,V) = 0.9362

The decision to classify the waste as hazardous waste or not was made by substituting the following values in the formulae for $\hat{W}$ $\hat{W}_{.80}$ of the previous section.

n = 24	r = 0.9362
$\bar{Y}$ = 4.5445	m = 10
$\bar{V}$ = 3.9351	$\bar{U}$ = 4.6876
S_v = 0.76896	S_u = 0.8663

Substituting the above data in appropriate equations yields the following results:

$\hat{W} = \exp [3.8138] = \exp [\tilde{V}] = 43.3$ ppm

$S\tilde{V}^2 = (0.1764)^2$

$\hat{W}_{.80} = \exp [3.8138 + 1.154 (0.1764)] = 55.6$ ppm

Since the STLC (100 ppm) for barium is much larger than the 55.6 ppm value calculated above, it was decided that the waste was not hazardous due to barium concentrations. Similar subsampling and calculations were performed for other heavy metals. On the basis of the results, it was similarly concluded that the waste material was not hazardous for all contaminants analyzed given California DOHS toxicity considerations.

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QUALITY ASSURANCE AUDITS OF FIELD SAMPLING ACTIVITIES

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INTRODUCTION

Data from monitoring and sampling programs cannot be evaluated and interpreted with confidence unless adequate quality assurance (QA) methods and procedures have been incorporated into the program design. Adequate QA requires identification and quantification of all sources of error associated with each step of the monitoring and sampling effort. The identified sources of error can then be analyzed using appropriate statistical tests yielding estimates of the various components of variance.

To date the most highly developed aspects of QA undertaken in support of monitoring and sampling programs deal with analytical procedures. Due to the complexity of designing adequate environmental monitoring programs, i.e., identification of a contaminant distribution in a heterogeneous environment such as the soil system, the QA applied to the analytical procedures, even though necessary, is not sufficient in itself to assess variability within the sampled environment. The analytical error may account for only a small portion of the total variance. It is clear that a comprehensive QA program is required for the sampling portion of a monitoring effort.

In 1979 the USEPA initiated a policy that required all USEPA laboratories, program offices and regional offices to prepare QA program plans for all monitoring and measurement activities that generate and process environmentally related data for agency use. In 1980 the USEPA's Office of Monitoring Systems and Quality Assurance (OMSQA) issued guidelines identifying specifications for preparing QA project plans.[1] These guidelines identify and describe 16 essential elements that all QA project plans must address, the format to be followed for addressing these elements and how the plans would be reviewed and approved.

One of the essential guideline elements identified is the requirement to conduct program audits. The following sampling and monitoring activities conducted by USEPA are examples of programs requiring high quality, decision making data. As such, they are required to have a comprehensive audit program.
- Emergency cleanup operations
- Remedial response operations
- Preliminary data collection investigations
- Enforcement data collection investigations
- Regulatory purposes
- Research and technology transfer studies

The principal function of the overall QA program is to assure that proper design techniques are being implemented and that adequate QA measures are being employed so that the resulting data will be of acceptable quantity and quality to satisfy program requirements.[2] The QA audit function is not intended to evaluate the technical merit or to verify the scientific validity of the sampling design, sampling devices or program protocols. Its purpose is to ensure that the methods and procedures identified in the programs, protocols and QA plan are in place and are being followed.

The QA audit function is not intended to threaten, intimidate or abuse sampling/monitoring personnel in the performance of their duties. It should, however, verify that specified operating procedures are implemented and maintained throughout the duration of the sampling program.

In this paper, the authors discuss those aspects dealing with program audits relating only to the sampling portion of the total monitoring program.

PURPOSE

As previously stated, the purpose of an audit is to ensure that the protocols identified in the Project Plan and QA Project Plan are in place and functioning well.

Specifically, the audit should:
- Verify that the sampling methodology and QA measures are being performed in accordance with program requirements
- Verify that project documentation is in order, i.e., records, chain-of-custody forms, analytical tags, log books, work sheets, etc.
- Verify the availability and presence of key project personnel and their qualifications
- Identify QA problems
- Recommend corrective actions, if necessary
- Follow-up on previous recommendations
- Provide a written report of the audit

An audit should normally be designed, announced in advance and planned with the Project Officer of the sampling program rather than being a surprise inspection. The reasons for this are:
- A surprise inspection may cause confusion among the field personnel and the other Agency observers
- A surprise inspection may hinder the field operations
- Due to the hazardous nature of many field projects, unannounced visits could increase the risk of accidents
- Key personnel and/or log books and sampling records may not be available

An unannounced audit would be advantageous only because of the element of surprise. Thus, there would be little time to correct any problems or deficiencies occurring. Unannounced audits

should be performed only if there is information indicating that there are serious problems with the sampling program.

AUDIT TEAM

The audit team should have at least two people. The size of the team will, of course, depend upon the extent of the operations being audited. However, any operations which are potentially hazardous should be performed using the buddy system.

As the disciplines required to perform sampling activities are quite varied, so too must the audit team have a variety of technical expertise.

Technical backgrounds required may include the earth sciences, chemistry, engineering, health and safety, biology and environmental science. As far as possible, the team should be composed of specialists having overlapping experience in various fields of science and engineering related to the project to be audited. The team also must consist of mature professionals. The process of reviewing other people's work and making constructive, objective evaluations requires that the team members have both characteristics. The additional aspect of a hazardous environment requires that personnel be alert, safety conscious and possess a high degree of professionalism.[3]

The audit team should report to an Audit Program Manager who has overall responsibility for the audit and review of the final report. The audit team leader, selected by the audit program manager, is primarily responsible for leading the team through preparation, the site visit and the preliminary report preparation.

AUDIT PROGRAM MANAGER

The Audit Program Manager should possess technical as well as managerial talents. Since the team must consist of professionals with a variety of scientific and engineering backgrounds, the background of the manager should be as multidisciplinary as possible, preferably centered around environmental science. At a minimum, it is recommended that the Audit Program Manager have a Bachelor's degree in a scientific or engineering field or equivalent related professional experience, three years of experience as an auditor and one year of experience as an audit team leader.[3]

The Program Manager selects team members and a Team Leader, makes assignments to individual members, assists the Leader where necessary in preparing for the audit and approves all plans and reports. He is additionally responsible for retaining all records and reports of the audit proceedings.

AUDIT TEAM LEADER

The Team Leader should be selected from team members who have participated in a number of audits and have demonstrated clear managerial and leadership qualities. At a minimum, it is recommended that the Team Leader have a Bachelor's degree or three to eight years of relevant work experience in a scientific or engineering field and two years of experience as an audit team member. The Team Leader receives his assignment from the audit Program Manager, helps select team members, makes assignments and leads the team in preparing, conducting and reporting the results of the audit.

AUDIT TEAM MEMBERS

Each team member should have a Bachelors' degree in an appropriate scientific or engineering discipline. In addition, each member should have at least one year of experience in performing field sampling. The team members work with the Leader in preparing for the audit, conducting the audit and reporting the results of the audit.

TRAINING

Audit team training should be similar to that required for other personnel involved in hazardous waste site/facility investigations. The following subject areas should be included in the personnel training program.[3]
- Performing an audit
- RCRA/CERCLA Regulations including the rights of inspectors and owner/operators of hazardous waste sites/facilities
- Safety protocols including removal, decontamination and disposal of clothing and equipment used during site visits and use and restrictions of clean areas
- Safety equipment including the use of respirators and self-contained breathing apparatus and protective clothing
- First Aid/Cardiopulmonary resuscitation
- Site-specific contingency and evacuation plans
- Legal ramifications of the audit including requirements of chain-of-custody, preservation of evidence and witness and testimony responsibilities[4]
- Risk assessment, recognition and evaluation of extent of hazards, methods used to control risks and chemical compatibilities/reactions
- Personal hygiene including prohibitions against eating, drinking and smoking and the effect of facial hair on respirators[5]
- Certification at the intermediate and/or advanced level of the USEPA's Health and Safety Training Program[6]

IN-HOUSE AUDIT PREPARATION

The audit team should prepare to conduct the audit by reviewing project documents including QA plan, protocols and progress reports. In reviewing the documents and preparing for the audit, checklists should be prepared which will aid the audit team in identifying procedures in the field which are crucial to the project goals. Preparations for the field audit/site visit should also include a review of health and safety requirements and field equipment needed for the audit. Final preparations should include communications with the Project Officer regarding the anticipated schedule, activities to be observed, any current problems and assistance with health and safety aspects including the availability of on-site safety equipment for the audit team.

Specific documents that should be examined include:
- Project plan
- QA Project plan and QA reports
- Protocols and methods
- Previous audit reports from other offices or agencies
- Project and progress reports
- Contract and proposals
- Documents to provide background information on the site (e.g., RCRA permit applications, preliminary assessment reports, groundwater monitoring plans, maps, photographs, etc.)
- Health and safety plan including contingency and evacuation plans
- Chain-of-custody procedures and documents

For projects involving RCRA-regulated sites, background documents should include the facilities Part A and applicable sections of the Part B permit (e.g., Waste Analysis Plan, Groundwater Monitoring Plan, etc.) applications. If the project involves a CERCLA site, a preliminary site assessment report or other information may be available.

The project documents should be reviewed to understand the overall project goals so that activities which are critical to those goals may be audited. Assignments for the team members should be based upon the site activities to be audited and the available team members' backgrounds. Assignments for the audit in-house preparation and field activities should be matched to the team members whose experiences best suit these assignments. For example, some assignments may require more experience and expertise in soils than in the engineering or geology disciplines.

The products of the in-house audit preparation should be the following:[3]
•Assignments for the team members during both the preparation and field audit phases
•Checklists to identify and verify performance of critical steps in activities
•List of equipment and supplies needed during the audit
•Schedule of activities for the site visit including the introductory meeting with senior field personnel, the various audit activities, a session for the team to prepare for the debriefing and the debriefing of site personnel

CONDUCTING THE AUDIT

Arrangements should be made between the Team Leader and the Project Officer for the site visit to conduct the audit. Prior to the site visit, a schedule of the audit which will not interfere with the project should be arranged. A list of recommended procedures to be followed when conducting the on-site sampling audit is found below.[3]

Do:

•Do, upon arrival at site, immediately identify audit team personnel to the Project Officer or most senior project person on site
•Do meet with the project personnel and review the intended work schedule identifying which on-site personnel and operations will be involved in the audit
•Do review all safety requirements, hazards and safety equipment which will be used on-site
•Do conduct the audit during normal working hours and at the convenience of the owner or manager of the site and the Project Officer

Do Not:

•Do not discuss judgments with site personnel
•Do not participate during the visit; the audit team members are strictly observers
•Do not hinder operations

After meeting with the on-site Project Officer and reviewing the audit schedule and tasks, each team member should start performing his audit functions using the checklists.

Whenever possible inventory the sample bank records and archived samples to verify that the documentation is in order and sufficient to establish the disposition of any sample collected. Trace the flow of specific samples through the system. Records to review include: Chain-of-custody (COC) forms, Sample Tags, Custody Seals, Shipment Forms, Logbooks and Archived Samples. Logs must be clear and concise. Logbooks changes made by field personnel should be initiated and lined through so that the original entry is still visible. Problems should be documented in the logs.

Verify personnel identified in the Project Plan, QA Plan and contract proposal. Include all managers, middle managers, professional specialists and first line field supervisors.

Observe activities carried out by the sample bank custodian(s). Before accepting custody of any samples, sample bank personnel should check to make sure that:
•Each sample has a completed sample collection tag attached
•Each sample is identified on the COC form
•A sample/site description form or record has been completed for each sample
•Discrepancies are corrected

Observe sampling and sample handling procedures first-hand. Sample handling procedures may include drying, sieving, mixing, compositing, splitting, packaging and shipping.

Observe housekeeping: safety, decontamination, accident documentation and security.

Observe sampling equipment and containers and the cleaning and storage of sampling equipment.

Observe the collection procedures preparation and frequency of collection of field blanks, replicates, splits and spikes if any.

Use the checklist while making these observations.

DEBRIEFING

The Audit Team Leader should first meet alone with the audit team members to review their results and determine what should be addressed at the debriefing. The review should address the following points, allowing team members to summarize their findings:
•Sampling activities and documentation
•Sampling bank activities and documentation
•QA problems
•Follow-up on previous recommendations
•Summary

Debriefing should be held between the audit team and project personnel deemed appropriate by the Project Officer.

In most cases, the Team Leader should conduct the debriefing and review the team's initial findings. The Leader may choose to let team members comment on their own findings. It should be made clear that the results of the audit are still tentative at this stage and that the final audit results will be reported in writing.

After each topic is discussed, allow project personnel to make comments. The Team Leader should request any further documentation he may need for the final report; resumes of new people, copies of additional protocols, etc.

Each team member should write a report on his findings. This should include a copy of the completed checklists. The reports are then assembled into a consensus document by the Team Leader and reviewed by the Audit Program Manager. The final revised report, signed by the Team Leader and approved for distribution by the Program Manager, is released to the office requesting the audit and the Project Officer.[3]

The report should include and clearly identify points which require corrective action. These should be in the form of recommendations.

ACKNOWLEDGEMENTS

This Paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

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MODELING MOBILIZATION AND FATE OF LEACHATES BELOW UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

There are four major exposure pathways for contaminants from uncontrolled hazardous waste disposal sites:[1] groundwater/leachate, surface water, contaminated soils and residual waste and air (Figs. 1 and 2). The environmental setting for an uncontrolled disposal site located above the water table is shown in Figure 1. The potential pathways to human and ecological receptors of Figure 1 are depicted in Figure 2. A variation of the above would be a site where the waste was buried below the water table; in this case, the leachate flume and groundwater are coincident. The exposure pathways are essentially the same in both cases.

Remedial actions are designed to reduce exposure to humans and the environment to acceptable levels either by containing pollutants originating from the waste site in place or by removing the hazardous substances from the immediate environment.

Modeling can play an integral role in waste cleanup and other environmental protection studies. A model is a decision tool which, if applied properly, can greatly assist decision-makers in effectively dealing with complex issues at uncontrolled waste sites. Today, five basic model categories are used: (1) emission models, to quantify release (quantity) or pollutant emissions in the environment (e.g., air emissions or leaching from a waste site; (2) fate models, to estimate concentrations of pollutants in the environmental media (e.g., fate of pollutants in the soil and groundwater); (3) exposure models, intended to convert environmental concentrations to ab-sorbed doses by humans (e.g., in inhalation); (4) risk models, known also as dose-response models, for the extrapolation of animal carcinogenicity data to humans and the estimation of probable human risks to cancer; and (5) cost/effectiveness models or analyses (e.g., mathematical optimization models) to estimate effectiveness (e.g., reduction of human risk) when imposing alternative actions or strategies (e.g., remedial actions) at waste sites.[2]

In this paper, the authors present information on leachate fate modeling in the soil and groundwater regimes below uncontrolled hazardous waste sites.

SOURCES, EMISSIONS, ENVIRONMENTAL PHASES

Soil and groundwater contamination are commonly encountered problems at uncontrolled hazardous waste sites; they result from the migration of leachates originating from a wide variety of waste management facilities including storage and treatment, landfills, surface impoundments, mines, waste piles and land treatment. Primary leachate and pollutant sources and waste modes are given in Table 1 and the sources and the associated pollutants are listed[3] in Table 3. The composition of the leachates produced depends principally on the type of wastes present and the decomposition in the waste site (aerobic or anaerobic).

Modeling mobilization of leachates from waste sites is a complex task; most often, the problem cannot be approached from a simplified perspective; for example, by employing a one-, two- or three-dimensional model that accounts for convection, dispersion, adsorption, retardation of decay of species in the soil or groundwater regime. Pollutant species of the leachates partition in the various phases of the soil matrix (Fig. 3), whereas the species phases, the environmental dynamics and the species chemistry are interactive at all times. This interaction governs the leachate migration and mobilization in the soil compartment, especially since secondary compounds are produced in the various phases of the soil matrix.

For example, landfills are principally disposal sites for municipal refuse and some industrial wastes. Municipal refuse is generally composed of 40 to 50% (by weight) organic matter, with the remaining mass consisting of moisture and inorganic matter such as glass, cans, plastic, pottery, etc. Under aerobic decomposition, carbonic acid that is formed reacts with any metals present and calcareous materials in the rocks and soil, thus increasing the hardness and metal content of the leachate. Decomposition of the organic matter also produces gases, including CO_2, CH_4, H_2S, H_2, NH_3 and N_2, of which CO_2 and CH_4 are the most significant soil contaminants.[3]
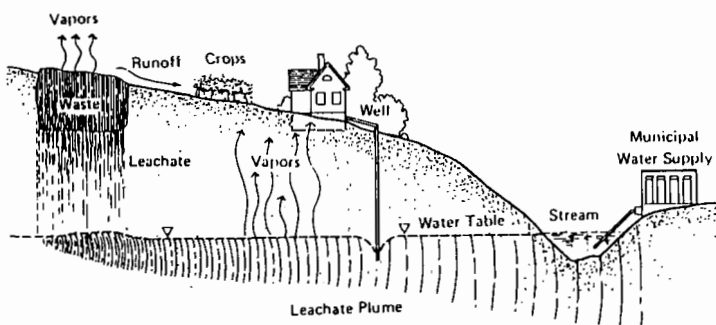
Figure 1
Environmental Pathways from a Generalized Hazardous Waste Site
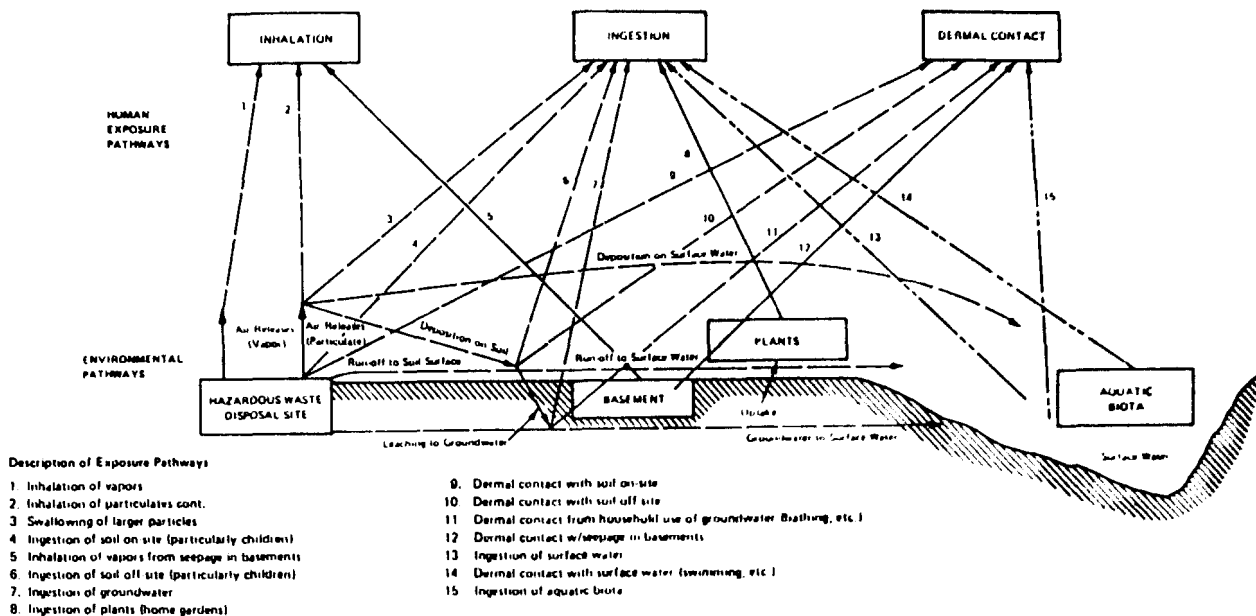
Figure 2
Exposure Pathways from a Hazardous Waste Disposal Site

Thus, modeling of mobilization and leachate below uncontrolled hazardous waste sites requires a thorough knowledge of the environmental factors and chemistry of the site.

ENVIRONMENTAL FACTORS AND CHEMISTRY

Soil zone modeling is a complex problem. A major characteristic of a soil subcompartment—as contrasted to water or air subcompartments—is that the temporal, physical and the chemical behaviors of this subcompartment are governed by "out-compartmental" forces such as precipitation, air temperature and solar radiation. This governance by external factors is also one of the main reasons why the mathematical modeling of leachate

Figure 3
Schematic of Phases in Soil Matrix

migration in soil can be much more complex than effluent or air modeling.

The chemical, physical and biological properties of a leachate in conjunction with the environmental characteristics of an area, result in physical, chemical and biological processes associated with the transport and transformation of the leachate in soil and groundwater. These processes are described in the following sections, along with some of the mathematical models described in the literature.

Physical Processes

The physical behavior of a chemical determines how the chemical partitions among the various environmental media; this partitioning has a significant effect on the environment fate of a substance. For example, the release into soil of two different acids (with similar chemical behavior) may result in one chemical volatilizing into the air and the other chemical adsorbing onto the organic material in the soil. The physical behavior of a substance, therefore, can have a significant effect on the environmental fate of that substance.

The processes and corresponding physical parameters that are important in determining the behavior and fate of small amounts of chemicals differ from forces governing chemical migration during large-scale releases (e.g., spills).

The processes of advection, diffusion, sorption and volatilization are most important to both trace-level analyses and large-scale release analyses. Bulk properties (e.g., viscosity and solubility) are usually only important in simulations involving large amounts of contaminants.

Sorption/Ion-Cation Exchange

Adsorption is the adhesion of leachate pollutant ions or molecules to the surface of soil solids, causing an increase in the pollutant concentration on the soil surface over the concentration present in the soil moisture. Adsorption occurs as a result of a variety of processes with a variety of mechanisms, and some processes may cause an increase of pollutant concentration within the soil solids—not merely on the soil surface. Adsorption and desorption can drastically retard leachate migration in soils; therefore, knowledge of this process is of importance when one is dealing with contaminant transport in soil and groundwater. The type of pollutant will determine to what kinds of material the pollutant will sorb. For organic compounds, it appears that partitioning between water and the organic carbon content of soil is the most important sorption mechanism.
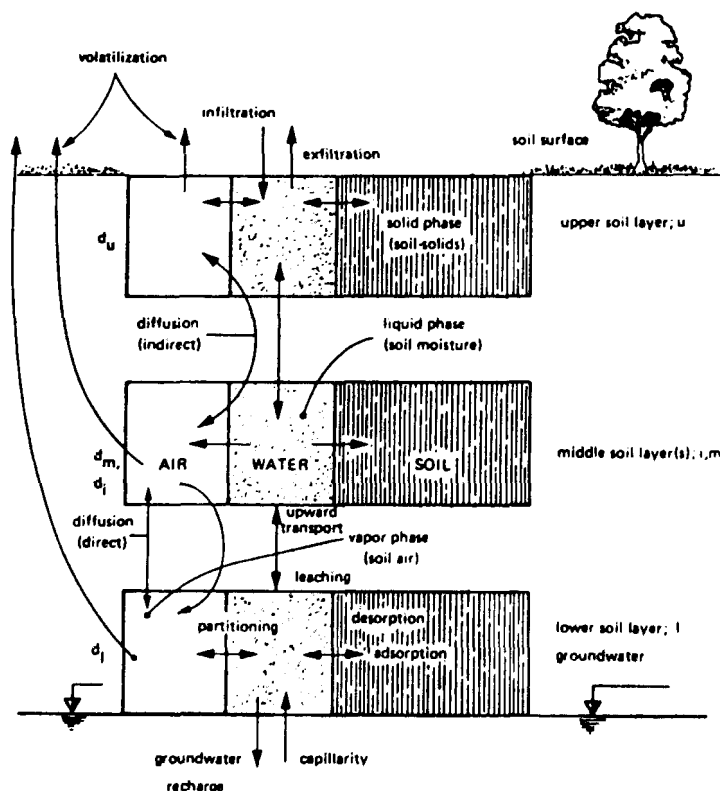
Table 1
Sources and Wastes

Pollutant Source	Wastewater Impoundments	Solid Waste Disposal Sites	Wastewater-Spray Irrigation	Land Application	Injection or Disposal Wells	Septic Tanks and Cesspools	Pits	Infiltration/Surface Runoff	Leaching from Storage Sites
Industrial									
Wastewater	X		X		X				
Sludge				X					
Solid Waste		X							X
Municipal									
Wastewater			X						
Sludge		X		X					
— Solid Waste		X							X
Household									
— Wastewater						X			
Agricultural Feedlot								X	
Mining	X	X			X		X	X	
Petroleum Exploration					X		X		
Cooling Water					X				
Buried Tanks, Pipelines									X
Agricultural Activities								X	X

Sorption and desorption are usually modeled as one fully reversible process, although ,hystersis is sometimes observed. Four types of equations are commonly used to describe sorption/desorption processes: Langmuir, Freundlich, overall and ion or cation exchange. The Langmuir isotherm model was developed for single layer adsorption and is based on the assumption that maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface, that the energy of adsorption is constant and that there is no transmigration of adsorbate on the surface phase. These models are thoroughly described in the literature;[4] therefore, no additional informatioan is provided here.

Ion exchange (an important sorption mechanism for inorganics) is viewed as an exchange with some other ion that initially occupies the adsorption site on the solid. For example, for metals (M + +) in clay the exchanged ion is often calcium.

$$M^{++} + [clay] \cdot Ca \rightarrow Ca^{++} + [clay] \cdot M \qquad (1)$$
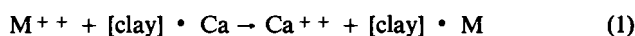
Cation exchange can be quite sensitive to other ions present in the environment. The calculation of pollutant mass immobilized by cation exchange is given by:

$$S = EC \cdot MWT/VAL \qquad (2)$$

where: S = maximum mass associated with solid (mass pollutant/mass of soil); EC = cation exchange capacity (mass equivalents/mass of dry soil); MWT = molecular (or atomic) weight of pollutant (mass/mole); VAL = valence of ion (−). For additional details, see the article by Bonazountas and Wagner.[5]

Diffusion/Volatilization

Diffusion in solution and volatilization from the soil-air to the atmosphere are processes that affect leachate migration of mainly volatile compounds. Many volatilization models are available in the literature, but some of these models can be applied only to specific environmental situations.[4]

Chemical Processes

The important chemical processes to be considered when modeling mobilization and fate of leachate are: ionization, hydrolsys, oxidation/reduction and complexation.

Ionization

Ionization is the process of separation or dissociation of a molecule into ions—particles of opposite electrical charge. The extent of ionization has a significant effect on the chemical behavior

Table 2
Primary Sources of Soil Contamination and Associated Pollutants

Source	Type of Pollutants
Industrial Sources	
Chemical manufacturers	Organic solvents
Petroleum refineries	Chlorinated hydrocarbons
Metal smelters and refineries	Heavy metals
Electroplaters	Cyanide, other toxics
Paint, battery manufacturers	Conventional pollutants
Pharmaceutical manufacturers paper and related industries	Acids, alkalines, other corrosives many are highly mobile in soil.
Land Disposal Sites	
Landfills that received sewage sludge, garbage, street refuse, construction and demolition wastes	BOD, inorganic salts, heavy metals pathogens, refractory organic compounds, plastics; nitrate; metals including iron, copper, manganese suspended solids
Uncontrolled dumping of industrial wastes, hazardous wastes	
Mining Wastes	Acidity, dissolved solids, metals, radio-active materials, color, turbidity
Agricultural Activities	BOD, nutrients, fecal coliforms, chloride, some heavy metals
Agricultural feedlots	
Treatment of crops and/or soil with pesticides and fertilizers; runoff or direct vertical leaching to septic tanks and cesspools	Herbicides, insecticides, fungicides, nitrates, phosphates, potassium, BOD, nutrients, heavy metals, inorganic salts, pathogens, surfactants; organic solvents used in cleaning
Leaks and Spills	
Sources include oil and gas wells, buried pipelines and storage tanks; transport vehicles	Petroleum and derivative compounds; any transported cnemicals
Atmospheric deposition	Particulates; heavy metals, volatile organic compounds; pesticides; radio-active particles
Highway Maintenance Activities	
Storage areas and direct application	Primarily salts
Radioactive Waste Disposal	
Eleven major shallow burial sites exist in U.S.; 3 known to be leaking	Primarily ^{132}CS, ^{90}Sr, and ^{60}Co
Land Disposal of Sewage and Wastewater	
Spray irrigation of primary, secondary effluents	BOD, heavy metals, inorganic salts, pathogens, nitrates, phosphates, recalcitrant organics
Land application of sewage sludge	
Leakage from sewage oxidation ponds	

of a chemical in a leachate. An acid or base that is extensively ionized may have markedly different solubility, sorption, toxicity and biological characteristics than the corresponding neutral compound. Inorganic and organic acids, bases and salts may be ionized under environmental conditions. A weak acid (HA) will ionize to some extent in water according to the reaction:

$$HA + H_2O \rightleftharpoons H_3O^+ + A^- \tag{3}$$
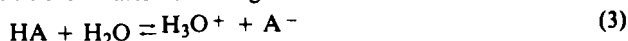
The acid dissociation constant K_a is defined as the equilibrium constant for this reaction:

$$K_a = [H_3O^+][A^-]/[HA][H_2O] \tag{4}$$

Note that a compound is 50% dissociated when the pH of the water equals the pK_a ($pK_a = -$ log Ka).

Hydrolysis

Hydrolysis is one of a family of reactions which transforms a leachate pollutant. Under environmental conditions existing at a waste site, organic compounds are the main chemicals hydrolyzed. Hydrolysis is a chemical transformation process in which an organic (RX) reacts with water, forming a new molecule. This process normally involves the formation of a new carbon-oxygen bond and the clearing of the carbon-X bond in the original molecule:

$$RX \xrightarrow{H_2O} R - OH + X^- + H^+ \tag{5}$$
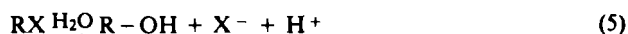
Hydrolysis reactions are usually modeled as first-order processes using rate constants (K_H) in units of (time.)[1]

$$-d[RX]/dt = K_H[RX] \tag{6}$$

The rate of hydrolysis of various organic chemicals, under environmental conditions, can differ by 14 orders of magnitude with associated half-lives as low as a few seconds to as high as 10^6 years. If laboratory rate constant data are used in soil models and not corrected for environmental conditions, as it often the case, then model results should be evaluated with skepticism.

Oxidation/Reduction

For some organic compounds of leachates (such as phenols, aromatic amines, electron-rich olefins and dienes, alkyl sulfides and eneamines), chemical oxidation is an important degradation process. Most of these reactions depend on reactions with free-radicals already in solution and are usually modeled by pseudo-first-order kinetics:

$$-d[X]/dt = K'_o [RO_2 \cdot] [X] = K_{ox} [X] \tag{7}$$

where: X is the pollutant, K'_o is the second order oxidation rate constant, $RO_2^=$ is a free radical and K_{ox} is the pseudo-first-order oxidation rate constant.

Complexation

Complexation, or chelation, is the process by which metal ions and organic or other non-metallic molecules (called ligands) can combine to form stable metal-ligand complexes. The complex that is found will generally prevent the metal from undergoing other reactions or interactions that the free metal cation would undergo. Complexation may be important in some situations; however, the current level of understanding of the process is not very advanced, and the available information has not been shown to be particularly useful to quantitative modeling.[3]

Biological Processes

Bioaccumulation is the process by which terrestrial organisms (such as plants and soil invertebrates) accumulate and concentrate pollutants from the soil. Bioaccumulation is not examined in soil modeling, aside from some nutrient cycle (phosphorus and nitrogen) and carboncycle bioaccumulation attempts.

Biodegradation refers to the process of transformation of a chemical by biological agents, usually by microorganisms. It includes a number of different processes such as: mineralization, detoxication, cometabolism, activation and change in spectrum. In toxic chemical modeling, biodegradation is usually treated as a first-order degradation process.[3]

$$dc/dt = -K_{DE} \cdot c^n \tag{8}$$

where: c = dissolved concentration of pollutant soil moisture ($\mu g/mL$); K_{DE} = rate of degradation (day^{-1}); and n = order of the reaction (n = 1; i.e., a first order reaction).

MATHEMATICAL MODELING

Leachate and pollutant fate mathematical modeling in soil systems is an area of current intensive work because of the numerous problems originating at hazardous waste sites. The variety of models has dramatically increased during the last decade. Although the numbers of models appears to be large, only a very few different modeling concepts exist and very few physical or chemical processes are modeled.

In general, soil/groundwater modeling concepts deal mainly with point source pollution and can be categorized as: (1) unsaturated soil zone (or soil), (2) saturated soil zone (groundwater), and (3) geochemical. The first two categories follow comparable patterns of mathematics and approach; the third enters into chemistry and speciation modeling as presented by Bonazountas.[3]

One effective way to account for all previously reported processes in a modeling study is to formulate a "compartmental" model that assumes pollutant equilibrium at all phases and between all compartments of the soil matrices shown in Figure 3. This formulation is achieved by applying: (1) the law of pollutant mass concentration for a representative species of the leachate over time, in each phase, in each compartment and for all processes (physical, chemical, biological) and (2) to seek a balance of pollutant masses of the various compartments at all times. The chemical dynamics of the model have to be supplemented with the hydrogeologic and, perhaps, the watershed dynamics of the overall compartment.

At this stage of scientific research, the most developed soil compartment model appears to be SESOIL: Seasonal Soil Compartment Model.[4] SESOIL is a user-friendly, mathematical soil compartment model designed for long-term environmental, hydrologic, sediment and pollutant fate simulations. It can describe: water transport (quality and quantity), sediment transport (quality and quantity), pollutant transport and transformation, soil quality, pollutant migration to groundwater and other processes. Simulations are performed for a user-specified soil column extending between the ground surface and the lower part of the unsaturated soil zone of a region (Fig. 4).

The simulations are based upon a three-cycle rationale, each cycle being associated with a number of processes. The three cycles are: (1) the hydrologic cycle which takes account of rainfall, soil moisture, infiltration, exfiltration, surface runoff, evapotranspiration and groundwater runoff; (2) the sediment cycle which takes account of sediment washload (from storms) and sediment resuspension (due to wind); and (3) the pollutant fate cycle which takes account of advection, diffusion, volatilization, adsorption and desorption, chemical degradation or decay, biological transformation, hydrolysis, photolysis (not operational), oxidation (not

Table 3

Compound	Calculated Amount of Compound Applied (April 1979)	Concentrations Measured (ppm) (July 1979)			
		Measured		Predicted	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
Chromium	2.92 $\mu g/cm^2$	0.80	1.0	0.15	0.005
Copper	3.24 $\mu g/cm^2$	0.20	0.0	0.16	0.0003
Sodium	8.64 × 10^3 $\mu g/cm^2$	0.89	114.0	85.6	142.0
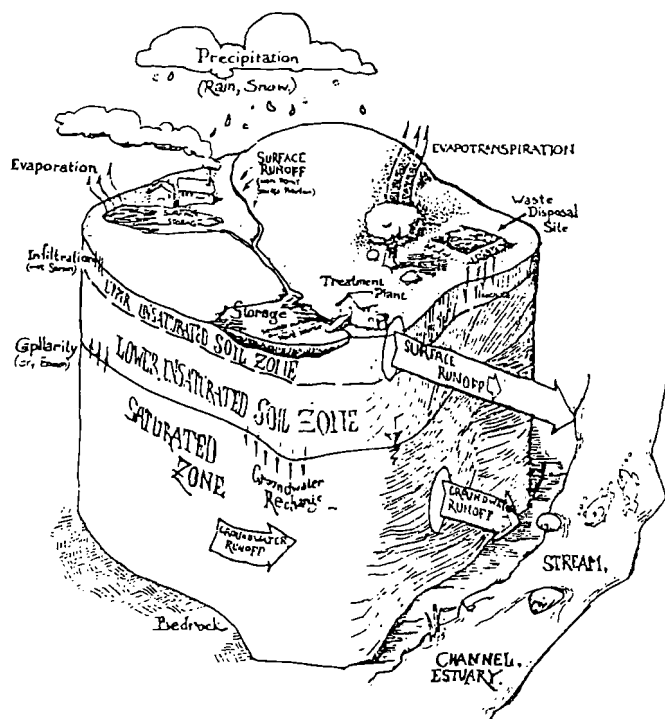
Figure 4
Schematic Presentation of the Soil Compartment (Cell)

operational), complexation of metals by organic ligands, cation exchange, fixation (not operational), nutrient cycles (not operational) and other processes. Model development has been sponsored by the USEPA. SESOIL model application and validation studies by its developers have been undertaken for land treatment practices,[5] for human exposure assessment studies related to groundwater contamination and for the fate of volatile solvents in soil systems.[6] The model has been tested and validated by many researchers.

CASE STUDIES

Two studies were performed on leachate mobilization and migration at uncontrolled waste sites: (1) leachate migration to groundwater from land treatment practices[5] and (2) leachate migration to the air of solvents leaking from barrels buried in the soil zone.[6]

Leachate to Groundwater—Land Treatment Practices

The land treatment site considered is the property of a plastics manufacturing plant. Manufacturing process wastes are treated in a secondary wastewater treatment system at the facility. Sludge from the wastewater treatment system is centrifuged to yield a sludge whose content is 5-10% solids; the resulting sludge is disposed of by land treatment.

In July, 1979, 5400 kg/ha of sludge were incorporated into the soil of a clean (i.e., not previously land cultivated) area of the site. The sludge was injected 12.7 to 20.3 cm below the soil surface and was subsequently mixed with the soil by ordinary farming methods.

The soil in the land treatment area is silt-loam, with a spatial intrinsic permeability of 7.05×10^{-9} cm^2 and a surface slope of 3%. Depth of groundwater is reported to be 30 to 70 m. The 40-year (1940-80) average annual rainfall is about 85 cm. The seven year rainfall (1973-80) is about 84 cm and last year's (July 79-August 80) rainfall was 79 cm. The average time of rain varies between 0.18 and 0.20 day for the above periods. The area receives 84-110 rainstorms per year. The rainy season is 365 days per year. The annual average temperature is 14 °C. Almost no surface runoff occurs at the site, due to both the climatic and the soil conditions.

Waste application occurred in the spring of 1979. In July, 1979, and a year later in August, 1980, soil core samples were collected

from 2 depths, 0 to 15 cm below grade and 15 to 30 cm below grade at both the waste application area and at a control area. The control area soil was nearly identical to the soil of the waste application area, except that no waste had been applied.

Soil core samples were air-dried prior to analysis. Analyses were performed on nitric-percloric acid digests of representative aliquots of the respective soil samples, so that reported results represent total metal concentrations and do not differentiate between adsorbed and dissolved analyte. Laboratory results are expressed as micrograms of analyte per gram of air-dried soil. Laboratory analysis of samples collected in August, 1980, is not yet complete.

Chemical data have been obtained from the literature and from site-specific investigations. No calibration has been attempted for the hydrologic cycle routine or for the soil parameters. The chemical parameters (adsorption coefficients) have been adjusted (by up to 20%) to calibrate the results.

The SESOIL was used to predict average concentrations of inorganic pollutants (Table 3). Predicted concentrations agree reasonably well with those values measured chemically, considering the uncertainty of all parameters affecting pollutant transport in soil compartments. A sensitivity analysis is being performed to study impacts of changes upon the soil compartment quality: (1) sludge application rates, (2) climatologic and soil parameters and (3) chemistry parameters. Results of the analysis are presented elsewhere.[5]

Leachate to the Atmosphere—Buried Solvents

The purpose of this research is twofold: (1) to understand—using a mathematical simulation—the long-term potential fate of the leachate of six solvents leaking from buried barrels disposed in soil systems, (2) to test the performance of the SESOIL model for highly volatile compounds. For this investigation, six halogenated organic solvents have been examined.[6]
- Perchloroethylene (Tetrachloroethene)
- Methylchloroform (1,1,1-Trichloroethane)
- Methylene Chloride (Dichloromethane)
- Carbon Tetrachloride (Tetrachloromethane)
- Freon 113
- Trichloroethylene (1,1,2-Trichloroethane)

It was not the authors' intention to conduct a site specific study; therefore, a number of hypothetical scenarios covering a wide range of U.S. climates, soils and solvents were considered. The methodology developed for the overall fate assessment is of general use and can be employed for similar studies or classes of pollutants.

The major conclusions of this analysis are shown in Table 4 and Figure 5. The fate of buried solvents was determined by simulation runs performed using SESOIL to determine the approximate pollutant mass of organics volatilizing, migrating to the groundwater or being entrained in the soil column after a period of ten years. This analysis yielded the following conclusions:
- Of all the chemicals studied, Freon 113 is most easily volatilized, whereas methylene chloride is least easily transported to the atmosphere.
- Methylene chloride contributes the most mass to groundwater; Freon 113 contributes the least pollutant mass to groundwater.
- The other solvents have fates intermediate between Freon 113 and methylene chloride and are fairly similar to one another. Under moderate conditions, 99-64% of their mass volatilized and 0.01-3% of their mass reached the groundwater. The remaining mass was captured in the soil column.
- Leaching to groundwater increases for chemicals with low Henry's law constants, low diffusion coefficients and low absorption coefficients. Leaching is generally favored by high rainfall and permeable soils.
- Volatilization is favored for chemicals with high Henry's law constants and high diffusion rates. It is generally enhanced by dry conditions and porous soil. Decreasing soil column depth generally results in increasing volatilization rates up to a certain depth. In this model version, volitilization appears to be the pre-
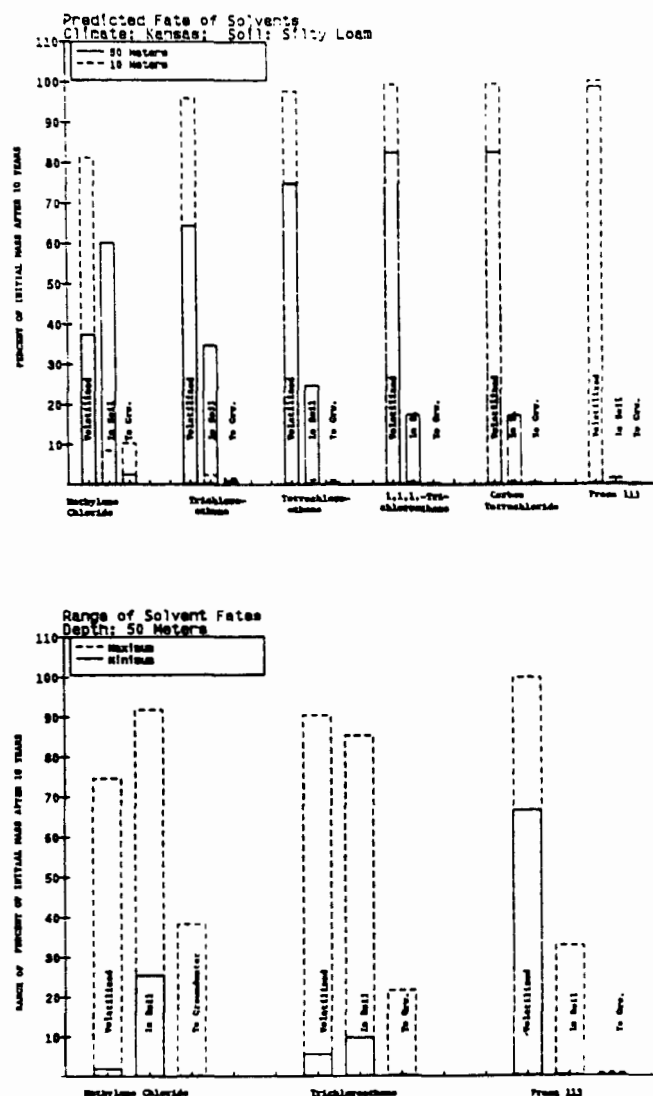
Figure 5
Predicted Ranges of Solvent Fates—Summary of Simulations

For the purpose of this paper, the authors have defined validation as "the process which analyzes the validity of final model output," namely the validity of the predicted pollutant concentrations or mass in the soil column (or in groundwater) to groundwater and to the air as compared to available knowledge of measured pollutant concentrations from monitoring data (field sampling). A disagreement of course in absolute levels of concentration (predicted versus measured) does not necessarily indicate that either method of obtaining data (modeling or field sampling) is incorrect or that either data set needs revision. Field sampling approaches and modeling approaches rely on two different perspectives of the same situation.

Table 4
Quantitative Fate of Solvents*

Chemical	% Volatilized	% Remaining in Soil Column	% Leached to Groundwater
Depth to Groundwater: 50 Meters			
Tetrachloroethene	74.9	24.7	0.4
1,1,1-Trichloroethane	82.4	17.3	0.3
Methylene Chloride	37.4	60.2	2.5
Carbon Tetrachloride	82.4	17.2	0.3
Freon 113	98.5	1.5	00.1
Trichloroethene	64.4	34.7	0.9
Depth to Groundwater: 20 Meters			
Tetrachloroethene	88.0	10.6	1.3
1,1,1-Trichloroethane	94.2	4.9	0.9
Methylene Chloride	57.0	33.8	9.2
Carbon Tetrachloride	94.3	4.9	0.8
Freon 113	99.6	0.3	0.01
Trichloroethene	82.4	14.6	3.0
Depth to Groundwater: 10 Meters			
Tetrachloroethene	37.8	1.1	1.1
1,1,1-Trichloroethane	99.3	0.1	0.6
Methylene Chloride	5?.2	10.3	8.5
Carbon Tetrachloride	99.3	0.1	0.6
Freon 113	99.9	0.01	0.01
Trichloroethene	96.0	1.6	2.3

1. Percentage of mass after 10 years, moderate climate, silty loam soil. Totals may not add to 100%.

* Percentage of mass after 10 years, moderate climate, silty loam soil. Totals may not add to 100%.

dominant removal process from the soil for all the chemicals studied.

•The actual quantities of mass removed by each pathway are strongly affected by the climate and soil type. Summaries of the pathways for all the six chemicals for a 10-year simulation period, a moderate climate, a silty loam soil and three depths of the soil column are given in Table 4. The range of all pollutant fates for all solvents considered and one typical climate, one soil type and two soil column depths is shown in Figure 5b. The fates of three solvents for all scenarios considered in this study (including sensitivity analyses of important variables), are shown in Figure 5b.

CONCLUSIONS

Mathematical modeling is an essential and powerful tool for assessing the mobilization and fate of leachate below uncontrolled hazardous waste sites. Models exist in the literature; however, they have to be appropriately selected and applied. Models have to account for the physical, chemical and biological processes of a site, although exact knowledge of the physics of the soil system—although essential—is impossible prior to employing any model. Model output validation is essential to any soil modeling effort, although this term has a broad meaning in the literature.

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IMPLEMENTATION OF A COOPERATIVE AGREEMENT TO INVESTIGATE AND REMEDY SURFACE AND GROUNDWATER CONTAMINATION AT THE BOULDER/ MARSHALL LANDFILL, BOULDER COUNTY, COLORADO

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INTRODUCTION

The inactive Marshall Landfill located in southeast Boulder County, Colorado, has been designated as the 81st site on the National Priorities List and is the highest ranked Superfund Site in Colorado. From approximately 1955 to 1974, both uncontrolled and engineered disposal of solid waste, liquid sewage sludge and septic pumpings and light commercial and industrial wastes have occurred at this facility. The adjacent Boulder Landfill, an engineered sanitary landfill accepting only solid waste, was opened in 1975.

These facilities (collectively referred to as the landfill) are located on the flank of Lake Mesa, a large pediment capped mesa. Natural seepage along the mesa flank has resulted in generation of approximately 30,000 gal/day of heavy metal and organic leachate which threatened to impact Community Ditch, a large irrigation and municipal water supply canal which traverses the inactive landfill. The landfill is also situated over a presumed recharge area for a major regional aquifer of the Denver Basin. Heavy metal and organic contamination has been detected in on-site and peripheral monitor wells within the alluvial aquifer.

In 1983, a Cooperative Agreement was signed between involved State and local regulatory agencies and impacted parties to investigate and remedy contamination at the landfill. In this paper, the authors discuss site conditions, the background and requirements of the Cooperative Agreement and the results obtained to date.

BACKGROUND

The Boulder/Marshall Landfill is located in southeast Boulder County, Colorado, approximately midway between the towns of Marshall and Superior, approximately seven miles southeast of the community of Boulder, Colorado and 20 miles northwest of Denver, Colorado.

Disposal History

The landfill consists of four distinct tracts (Fig. 1):
- An abandoned landfill operated as an open dump from approximately 1955 to 1970.
- The inactive Marshall Landfill operated by Urban Waste Resources from 1970 to 1974.
- Associated septic pumpage disposal ponds operated by Urban Waste Resources from approximately 1970 to 1975.
- The active Boulder Landfill and associated gravel mining operation, first opened in 1975 by Urban Waste Resources and subsequently sold to Landfill Inc. in 1976.

Landfill Inc. subsequently permitted an above grade expansion which is expected to keep the active Boulder Landfill in operation until 1990.

The Boulder/Marshall Landfill is located along the flank of Lake Mesa, a broad upland pediment surface. Refuse in the active landfill is placed across the top of Lake Mesa. Refuse within the inactive landfill was placed along the flank of Lake Mesa, down into the Cowdrey Drainage and up along the bedrock slope north of the drainage.

Although the landfill was intended primarily for domestic, municipal and light commercial solid wastes only, several other materials including untreated municipal sewage sludge from the City of Boulder were also disposed of at the landfill. From 1972 to 1974, while the city's waste treatment plant was being upgraded, sludge was co-disposed with the solid wastes by excavating slit trenches within previously placed solid wastes and emptying the nearly 80% liquid sewage sludge directly into the refuse. Septic tank pumpings were also dumped in a series of unlined open pits
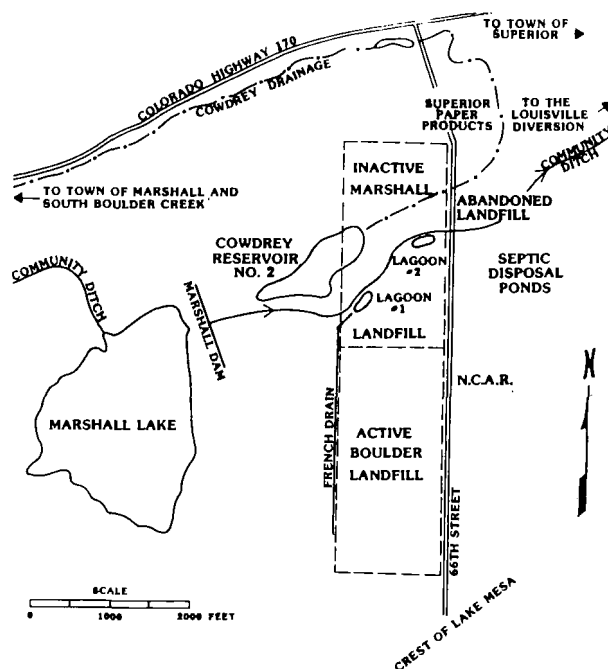
Figure 1
Site Plan of the Boulder/Marshall Landfill

along the east side of the landfill between 1970 and 1975. Co-disposal of septic pumpings with the refuse may also have occurred. Finally, records at the County Health Department indicate that industrial chemicals, primarily organic solvents, were co-disposed with the refuse until 1975.

Surface Water Systems

The Boulder/Marshall Landfill area encompasses two major surface water systems, the Marshall Lake-Community Ditch system and the Cowdrey Reservoir No. 2—Cowdrey Drainage System. Marshall Lake was created by the construction of Marshall Dam in 1909 to provide irrigation supply for farmers in eastern Colorado and peak municipal demand for the City of Louisville. Inflow into the Lake is derived primarily from Community Ditch which collects surface water from South Boulder Creek near the town of Eldorado Springs approximately 4 miles to the west of the landfill. Outflow from the lake occurs as flow along Community Ditch, seepage beneath the dam into Cowdrey Reservoir No. 2, and seepage into the alluvial and bedrock aquifers.

From Marshall Lake, Community Ditch traverses the southern portion of the inactive landfill and then straddles the northwest flank of Lake Mesa to a point one mile northeast of the landfill where it joins the Louisville Ditch. From there the water flows either into Louisville Ditch to the Louisville treatment plant or continues flowing in Community Ditch. Currently, flow in Community Ditch is limited to the late spring and summer months during peak demand for irrigation water. Maximum flow rate has been recorded at 86 cfs.

Cowdrey Reservoir No. 2 is supplied primarily by seepage beneath Marshall Dam with a lesser contribution from runoff from the surrounding area and seepage from the landfill. Outflow from Cowdrey Reservoir No. 2 occurs primarily as surface flow through Cowdrey Drainage. Due to the low gradient of this drainage, approximately 1 to 5 ft/1000 ft, the drainage does not possess a well-defined channel. Rather, it consists of a series of stagnant ponds and marshes which eventually drain into South Boulder Creek.

Hydrogeology

Five distinct water-bearing units have been identified beneath the landfill. These include an alluvial aquifer and four distinct sandstone units.

The alluvial aquifer consists of: sands, gravels and clays mantling the top and flank of Lake Mesa; colluvial material along the base of Lake Mesa; weathered bedrock in the low areas around Cowdrey Reservoir No. 2 and Cowdrey Drainage; and alluvium along Cowdrey Drainage. Inflow into the alluvial aquifer in the vicinity of the landfill generally results from groundwater recharge along the top of Lake Mesa and subsequent lateral flow to the north-northwest, entering the landfill area along the southern and eastern boundaries. In addition, a minor contribution to flow beneath the landfill occurs along the central portion of the western boundary of the active landfill due to recharge from Marshall Lake. In 1975, a French Drain was constructed along the west side of the active landfill to intercept this flow.

Discharge from the aquifer occurs primarily as surface seepage along the slope above and on the south side of Community Ditch where the water table intersects the ground surface. When this investigation began, this seepage either collected in the two lagoons and evaporated or flowed into Community Ditch; flowed over the inactive landfill, via the Lagoon No. 1 to discharge pipe across the ditch and eventually into Cowdrey Reservoir or Cowdrey Drainage; or seeped directly into Community Ditch. The remaining flow in the alluvial aquifer exits the area as seepage into or subsurface flow along Cowdrey Drainage.

Immediately beneath the alluvial aquifer is a shallow bedrock aquifer consisting of thin sandstone layers. This aquifer is separated from the overlying alluvial aquifer by thin organic rich clays and weathered claystone. In addition to the shallow bedrock aquifer, at least three other saturated zones were known to occur immediately (100 to 200 ft depth) beneath the landfill. These are the "A" and "B" sands of the lower Laramie Formation and the Milliken Sandstone of the Fox Hills. Together, these three units make up the Laramie-Fox Hills (L-F) aquifer, a major regional aquifer of the Denver Basin. Flow within the bedrock aquifers is complicated by extensive high angle faulting. Prior to this investigation, no information was available on the potentiometric surfaces of these strata, on their hydraulic interconnection, or their relationship with the overlying alluvial and shallow bedrock aquifers. However, it was known that the landfill was situated over the recharge area for the regional L-F aquifer. It was the potential threat to this aquifer, along with the potential impact to the municipal water supply flowing in Community Ditch, that led the Colorado Department of Health to nominate the inactive Marshall Landfill as the highest priority Superfund site in the State.

Water Quality

Previous water quality monitoring had indicated that existing leachate, surface water and groundwater contamination were dominated primarily by elevated concentrations of total dissolved solids, iron, manganese and phenolic compounds. Secondary components of surface and groundwater contamination at the landfill included barium, lead, cadmium, arsenic, mercury; cyanide; benzene; phthalate esters; and various volatile organics including chlorinated hydrocarbons such as dichloroethylene, methyl chloride, methylene chloride, trichloroethylene and tetrachloroethylene.

Although these substances had been detected in Community Ditch immediately downstream of the landfill, none were detected at the point of diversion to the Louisville water system or in the raw water storage for the Louisville water treatment plant. In addition, due entirely to a lack of monitoring, no impact to the regional L-F aquifer had been documented.

THE COOPERATIVE AGREEMENT

To ensure involvement in any investigation or cleanup at the landfill, a Cooperative Agreement to study and remedy contamination at the landfill was developed and entered into on June 6, 1983 between:
1. The Commissioners of Boulder County, Colorado
2. The Colorado Department of Health (CDH)
3. Farmers Reservoir and Irrigation Company (FRICO)
4. City of Louisville, Colorado
5. Landfill Inc. (LI), the current operator of the active Boulder Landfill

Not one of these parties was a generator of wastes disposed at the landfill; however, all of them perceived potential damages resulting from the existence or threat of surface or groundwater contamination.

The Cooperative Agreement was structured after the National Contingency Plan (10 CFR 300) and set forth a three-phased program of investigation and remedial action:

Phase I—Initial Remedial Measures (IRM)

• Design and install a 60 in. pressurized raw water pipeline along Community Ditch through the landfill area
• Design and construct a seepage control system to prevent surface and groundwater contamination due to leachate seepage
• Design and construct a monitoring program to evaluate the effectiveness of these two initial measures

Phase II—Remedial Investigation (RI)

• Complete an investigation of possible groundwater contamination in the landfill area

Phase III—Feasibility Study (FS)

• If any groundwater contamination presenting a hazard to human health or the environment is detected, identify any cost-effective remedial measure

•Design a monitoring system to identify any sources of surface and/or groundwater contamination which are not effectively contained, isolated or neutralized by the initial or final remedial measures.

Funding for these actions was to be obtained through a complex formula. Installation of the pipeline was to be funded in part by the City of Louisville and in part by Boulder County. Louisville was to contribute monies equivalent to those necessary to install a 27 in. diameter pipeline that had previously been proposed as a means of protecting only its portion of the ditch waters. Boulder County could draw from an existing environmental "sinking fund" created from a surcharge on disposal fees at the landfill and monies contributed by the current operator. This would fund the difference in the costs between the 27 and the 60 in. pipelines. FRICO was responsible for all maintenance and repair once the pipeline was installed and certified.

Funding for the seepage control system, monitoring of the Initial Remedial Measures (IRM), the Remedial Investigation (RI) and the Feasibility Study (FS) was the sole responsibility of Landfill Inc. Upon completion of these activities, LI was eligible for a 50% reimbursement for these costs. The reimbursement was to be drawn from the "sinking fund." If no remedial actions were required, LI was eligible for 100% reimbursement for the RI/FS subject to fund availability. If remedial actions were required, LI could perform these actions at its own cost, subject to later reimbursement as monies became available in the "sinking fund." This would also make LI eligible for 100% reimbursement for the RI/FS. Alternatively, should LI decide not to perform the remedial actions, this responsibility would fall to Boulder County. LI would then be eligible for only a 50% reimbursement for the RI/FS costs until the remedial actions were completed and "sinking fund" money again became available.

INITIAL REMEDIAL MEASURES

Within one year of the signing of the Cooperative Agreement, the raw water pipeline had been designed, installed and tested. This work was supervised by the County, Public Works Department, City of Louisville Public Works Department and FRICO. Final certification has been delayed due to minor deficiencies related to valving and right of way.

An integrated surface water management system was designed, and construction of this system was also initiated. Although a conceptual seepage control system was presented with the surface water management system, construction of this system has been deferred. This was done to allow integration of the seepage control system with any remedial actions that may be proposed under the FS. Monitoring of the effectiveness of pipeline installation has been achieved by pressure testing the pipe and monitoring the flow and chemical quality of the underdrain discharge.

REMEDIAL INVESTIGATION

The Remedial Investigation consisted of three distinct tasks performed within a phased approach. This work was supervised by a study group composed of representatives of the Boulder County Health Department, CDH, LI and Fox Consultants. The USEPA maintained indirect involvement with this group through an advisory role to CDH. A phased investigation was adopted where the uppermost saturated zone was characterized first; successively deeper saturated zones would be characterized only if the overlying zone was contaminated.

Task 1 required a literature review of all previously collected geologic, monitoring and operational data. This task was completed prior to the signing of the Cooperative Agreement and served as a basis for scoping all of the investigative activities and for design of permanent monitoring program for the entire area.

Task 2 consisted of all field investigations and laboratory analyses. Under this task, 32 new piezometers and monitor wells were installed; aerial photography was obtained and a topographic base map and well survey network were developed; and 70 new and existing wells, piezometers and methane probes were examined, developed, stabilized and monitored for field parameters including temperature, pH, conductance, dissolved oxygen, explosive gases and volatile organics (using a photo-ionization detector); water levels were measured on a monthly or bi-monthly basis; and 23 water and leachate samples were collected and submitted for full priority pollutant analysis.

All of these activities were completed, and a basic data report describing the results of these activities and the procedures used was developed and distributed within five months of the signing of the Cooperative Agreement.

Task 3 consisted of interpretive efforts related to site characterization and contaminant generation and migration assessment. A report summarizing the geology, hydrogeology, refuse conditions, hydraulic structures, water quality and contamination characterization was prepared and distributed seven months after the signing of the Cooperative Agreement. Significant conclusions contained in this report included the following:

•There appears to be a minimum of 50 to 60 ft of shale and minor interbedded sandstone between the alluvial aquifer and the Laramie-Fox Hills aquifer beneath the site.

•Where piezometers have been completed in all four water bearing horizons, the potentionmetric surface of the uppermost portion of the regional L-F aquifer, the "B" sand is above the alluvial water table and above the ground surface.

•The major water bearing units are separated from one another by low permeability aquitards which are a minimum of 20 ft thick.

•Approximately 15 to 25 ft of alluvium remains below the active landfill; however, only 0 to 5 ft remain beneath the inactive landfill. As a result, saturated refuse can be found throughout the inactive landfill, particularly south of Community Ditch and in a small area in the southernmost portion of the active landfill.

•For much of its length, the base of the French drain is above the water table; however, along its northern portion it appears to collect both contaminated and uncontaminated water.

•Both Lagoon No. 1 and Lagoon No. 2 discharge some overflow into Community Ditch. This was solved by installation of the 60 in. pipeline.

•There was no detected impact on the Marshall Lake-Community Ditch System as a result of contamination at the landfill. Contamination of Cowdrey Reservoir No. 2 appears to be limited to elevated concentrations of total dissolved solids and major ions.

•Groundwater contamination is characterized by: elevated concentrations of total dissolved solids and major ions; increased levels of trace metals including barium, iron, and manganese; and volatile organics, principally chlorinated hydrocarbons and monocyclic aromatics.

•Volatile organic contamination off-site occurs at concentrations an order of magnitude below those found on-site.

•The principal pathway for potential off-site migration of contamination is within the alluvial aquifer along the east side of the inactive landfill and along Cowdrey Drainage.

Subsequently, a second phase of investigation was conducted during the summer of 1984 to answer questions related to the shallow bedrock aquifer, the northern portion of the inactive landfill, the septic pumpage disposal ponds and off-site contaminant migration within the alluvial aquifer. At this time, only preliminary results are available. Several conclusions may be drawn.

•The shallow bedrock aquifer and deeper bedrock aquifers are generally isolated from the contamination within the alluvial aquifer by upward flow gradients and/or low permeability (10^{-5} to 10^{-7} cm/sec) clay shales.

•Contamination originating in the septic disposal area and the northern portion of the inactive landfill displayed organic contaminant concentrations one order of magnitude higher than those observed elsewhere in the area.

•Off-site contamination appears to be limited to the immediate vicinity of the landfill (i.e., within 100 to 200 ft. of the boundary)

and there is no evidence of a major contaminant plume off-site within the alluvial aquifer.

FEASIBILITY STUDY

Work on the FS will begin in September, 1984, once amended basic data and contaminant assessment reports are completed. At this time three major types of remedial actions are being considered: (1) surface controls, primarily surface water diversion, regrading and upgrading of the existing landfill cover; (2) groundwater source controls, principally interceptor wells/trenches and/or impermeable barriers; and (3) leachate collection and treatment using air stripping and/or carbon absorption.

CONCLUSIONS

The Cooperative Agreement offered a method whereby involved, concerned and impacted parties could have direct participation in remedying a longstanding environmental problem. Through the Agreement, the Colorado Department of Health was able to initiate and be closely involved in the investigation and mitigative actions at the State's top priority Superfund site. This agreement was consummated prior to any formal legislation authorizing Colorado to participate in Superfund and at a time when it appeared that the legislature might not authorize the State's 10% contribution to the fund.

Boulder County took a lead role in resolving a longstanding major environmental problem in what was otherwise known as a progressive and "environmentally conscious" community. In addition, the Cooperative Agreement afforded them a means of "gracefully" supporting the much needed expansion of the Boulder Landfill at a time when the community perceived it to be a major environmental threat.

The City of Louisville and FRICO have experienced major benefits from the installation of the pipeline. These include not only the protection of their water supplies, but also integration of the pipeline with existing capital improvements projects. Louisville was able to incorporate the pipeline into its overall program of expanding its water supply and water treatment system. FRICO was able to integrate the pipeline into program for upgrading the Marshall Dam outlet works and a long-term program of concrete lining the entire Community Ditch system.

Landfill Inc. has received benefits from its involvement in the Cooperative Agreement. First, it successfully obtained a permit to expand its facility, thus avoiding the loss of the capital investment in the expansion plan and permit applications. Second, direct involvement and control in the investigation provided a means of control on the activities and expenditures. Third, indirect association with a bad site and related potential negative public perception, which may have affected other operations in the state, was averted and converted into positive public opinion and local government support.

In summary, a group of parties not directly responsible for problems at the landfill but aware of potential negative impacts resulting from the problems at the site, was able to fashion an agreement to remedy this problem that was mutually acceptable and beneficial to all. Although modeled after the NCP, this Agreement was developed and implemented without direct involvement by the USEPA.

INVESTIGATION AND CORRECTIVE ACTION: HOW IT WAS DONE AT A SUPERFUND SITE IN CONNECTICUT

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INTRODUCTION

The degree of risk or threat posed by any landfill to adjacent populations is highly dependent on site-specific conditions such as hydrogeology, materials disposed and local resource demands. While a general understanding of potential risks can be obtained from a preliminary analysis, often this determination may be misleading without site-specific information. This was the case with the Laurel Park Landfill in Connecticut.

Initial evaluations, based on assumed hydrogeologic conditions, had predicted significant impacts to downgradient private water supply wells. However, a detailed and comprehensive site investigation produced evidence indicating that the initial model did not represent the site, and that potential impacts associated with leachate migration from the Laurel Park Landfill could be quickly and efficiently controlled by the installation of a perimeter toe drain.

Of particular interest in this investigation was the bedrock evaluation program. Early in the investigation, it was discovered that an understanding of the bedrock aquifer was key to a determination of leachate migration pathways and potential impacts to groundwater. Toward this end, Hart Associates initiated a comprehensive program design to evaluate bedrock fracture system, degree of weathering, presence of leachate in fractures and migration pathways available in the bedrock aquifer. The program consisted of test borings, rock cores and the construction of two extensive trenches on the east and south sides of the landfill.

BACKGROUND

The Laurel Park Landfill is located at the top of Huntington Hill near Naugatuck, Connecticut (Fig. 1). The site consists of about 30 acres, of which 19 are covered by fill. The property has been the site of waste management activities since the late 1930s. Until the mid-1960s, the site received a combination of industrial and municipal wastes. Since then, the site has received only municipal wastes. West of the site is Naugatuck State Forest. North, east and south of the site are approximately 40 homes served by individual private wells.

FIELD INVESTIGATIONS

In this section, the authors briefly describe the variety of field investigations undertaken at the Laurel Park Landfill between Nov. 23, 1982 and Jan. 18, 1983. While the original intent of the investigation was to evaluate the effectiveness of a glacial till layer in preventing vertical migration, it was discovered early in the investigation that the till was not as extensive as thought and consequently the goals of the investigation shifted to defining the hydrogeologic characteristics of the bedrock and hydrodynamics of the landfill.

Test Boring and Well Installation Program

A test boring program was conducted to define the thickness of the landfill, identify the types and characteristics of the materials underlying the landfill, locate the bedrock surface and generate subsurface sections. Four test borings were drilled through the landfill, using a combination of hollow stem augers and mud rotary (Fig. 2). Boring FTW-1 was intended to pass through the landfill, through the till and sample the bedrock surface. This process required driving casing through the landfill materials, installing a bentonite seal, then inserting a smaller diameter casing through the remaining soil materials. This double casing technique was designed to prevent landfill material from reaching the bedrock. A 5
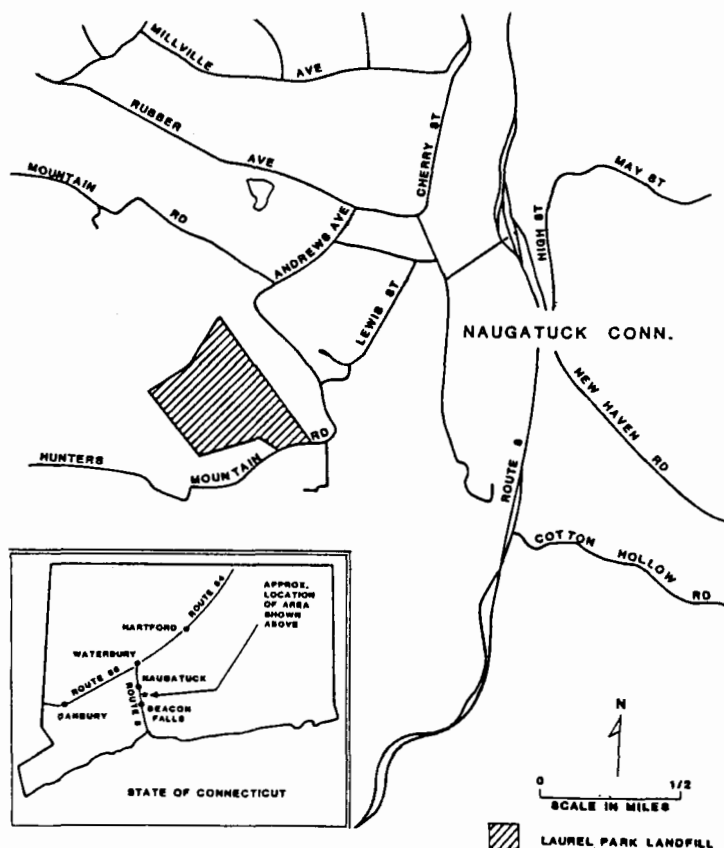
Figure 1
Regional Location of Laurel Park Landfill

ft rock core was obtained to observe the physical condition of the bedrock.

In addition to the four borings on the landfill, another boring (TB-1) was drilled near the western base of the fill. This boring went through an extensive fill layer and was finished as a well screened at the till/bedrock interface. A 5 ft rock core was obtained in this boring to verify that bedrock, rather than a boulder, had been reached.

Three of the fill borings were finished as wells (Fig. 2). The purpose of installing wells within landfill materials was to provide information pertaining to leachate behavior and character (i.e., contamination source). This process included determining the saturated thickness of the leachate in the landfill, the direction and gradient of leachate movement and the fluctuation of leachate levels in response to precipitation. These wells were also used to sample leachate for chemical characteristics.

Typical fill well construction is shown in Figure 3. Before installing any landfill wells, a layer of bentonite pellets was placed in the bottom of the borehole which extended several feet above the bedrock/till interface. This was done to prevent leachate migration through the bore hole. Wells consisted of 2 in. diameter flush joint PVC screens and casing which were installed through the augers. Sand or gravel packing was placed in the annular space around the well casing and brought to within 6 to 10 ft of the surface. A bentonite seal was placed on top of the sand pack, and the remaining annular space was filled with cement grout. A protective casing with locking cap was added as a final step. Water level monitoring of these wells showed fluctuations in leachate levels, indicating that these wells are in communication with the landfill and are functional observation wells.

Test Pits and Trenches

Seven test pits and two trenches were constructed to gain further understanding of the character and extent of the till and to determine the conditions of the bedrock. Each test pit was dug to a depth of 10 ft with a tractor-mounted backhoe. Samples were obtained from the side walls, and the pits were logged by the super-
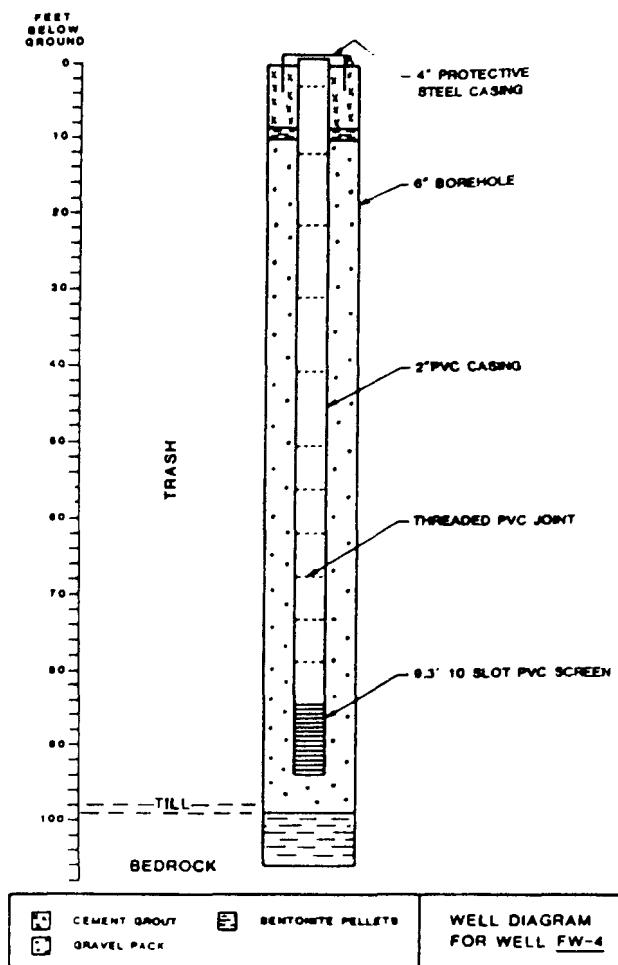
Figure 3
Well Diagram for Well FW-4
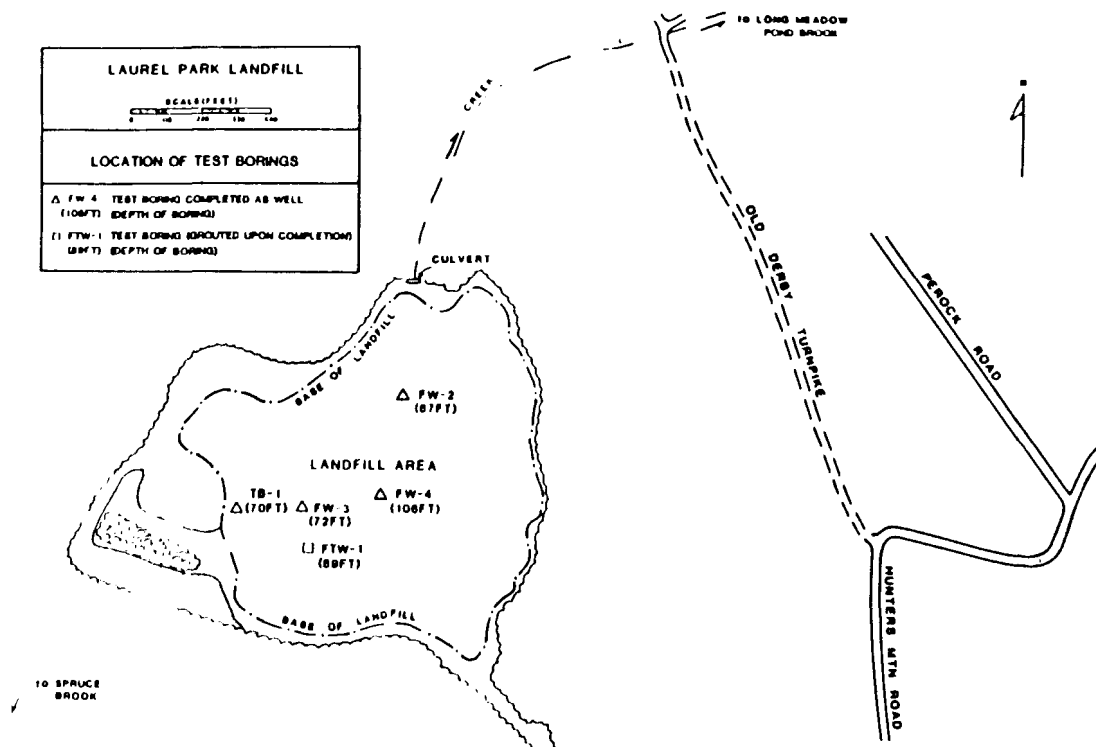
Figure 2
Laurel Park Landfill
Location of Test Borings

vising geologist. A shallow well was installed in each pit before backfilling. Soil encountered in all pits was very consistent, consisting largely of gray silty and clayey medium to fine sand. The till soils were found to be very dense. Bulk samples were obtained from three test pits and sent to a soils laboratory for permeability analysis. Permeability ranged from 6.8×10^{-5} to 1.5×10^{-6} cm/sec.

Trenches were used because they are an effective means of providing a continuous horizontal exposure of soil or rock along a given line or cross section. One trench was excavated along the entire southern side of the landfill with a bulldozer, and another trench was excavated along the entire eastern side with a backhoe. The south side trench showed that bedrock was within three to four feet of the surface and that the bedrock exposed was relatively unweathered Straits Schist. The east side trench was 1400 ft long and also exposed Straits Schist with unusually consistent foliation orientation.

Surface Runoff Measurements

The drainage conditions at the Laurel Park Landfill were such that a major portion of site runoff discharged to a small creek on the north side (Fig. 4). In order to estimate the various components of flow contributing to the runoff volume, this stream (which originated at the landfill) was chosen for a measuring location. An 18 in. diameter corrugated pipe was installed at the streams discharge point from the site and an earthern dam was constructed so that all surface runoff from the landfill exited through the pipe. Measurements of flow were made by placing a 5 gal pail beneath the pipe and recording the amount of time required to fill it.

The information developed clearly indicates that the vast majority of precipitation that falls on the site exits as surface runoff rather than infiltrating to form leachate. The discharge measurements at the culvert (from Nov., 1982 to Jan., 1983) closely correlated with rainfall events, indicating the immediate response of surface runoff to precipitation. During periods of no precipitation, the average culvert flow of 3.2 gal/min consisted predominantly of leachate.

Seep Mapping and OVA Field Screening

During the field investigation, major leachate seeps were mapped. The information, in conjunction with data on leachate evaluations in wells, provided further understanding of the hydraulic properties of the landfill. Only leachate seeps with obvious discharge points and definitive evidence of past or present flow were mapped. The vast majority of leachate seeps were located at or near the base of the fill. The most active seeps were located near the northern base of the fill. These formed a horizontal line approximately 3 ft above the base of the fill and flowed continuously. Seeps along the east side consisted of isolated outbreaks and flowed intermittently. When leachate seep elevations were correlated with leachate elevations in the wells, it was determined that the leachate body in the landfill sloped northward similar to. the bedrock surface base of the landfill and was discharging at the base of the northface.

Field screening with an Organic Vapor Analyzer (OVA) was also conducted for the primary purpose of detecting leachate seeps downgradient from the landfill. A perimeter survey was conducted to measure total airborn hydrocarbons. There were no leachate seeps detected anywhere beyond the immediate base of the landfill.

Electrical Resistivity Survey

Two electrical resistivity survey runs were conducted along the east side of the landfill. These surveys used the horizontal profiling approach in which a constant electrode spacing of 40 ft was maintained. It was thought that by comparing resistivity values for unknown areas to values obtained for an area known to be uncontaminated, areas of possible contamination could be identified. However, many factors affected the resistivity values, including depth to bedrock, amount of moisture present in the soil and the characteristics of the saturating fluid. Therefore, electrical resistiv-
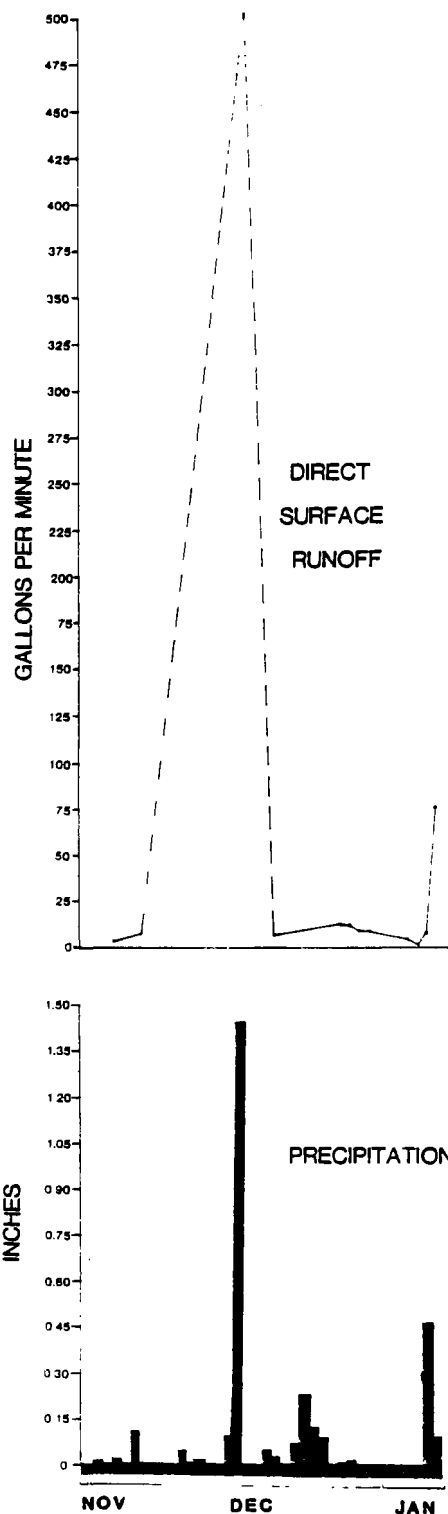
Figure 4
Relationship Between Surface Runoff and Precipitation

ity surveys were used merely as a field screening technique and were followed by more detailed investigations.

For the first run, apparent resistivity values ranged between 800 and 4,000 ohm-ft. Because of the variation between shallow bedrock and moist soil conditions, interpretation was difficult. Low values measured in an area of surface runoff from the landfill may be due to shallow soil contamination. The tentative conclusion reached using the resistivity survey was that runoff from the landfill is effecting shallow soil in certain areas east of the landfill.

Bedrock Evaluation Program

Through the test boring program, it was discovered that portions of the east, northern and southern sections of the landfill were either resting on a thin till soil layer covering the bedrock or were directly on the bedrock. Thus it was decided to further evaluate the characteristics and configuration of the bedrock surface in the immediate vicinity of the landfill, as the condition of this surface would be critical to the assessment of the potential for contaminant migration from the landfill through the bedrock aquifer.

In a bedrock aquifer, the principal conduits for groundwater flow are the joints and fractures. It was reasoned that if the Laurel Park Landfill is resting on the bedrock surface, and if leachate is entering the bedrock, then cracks or joints immediately adjacent to the landfill edge would be the first to show signs of contamination. The evaluation program consisted of constructing two trenches (Fig. 5) and then carefully cleaning the rock at select locations (using shovels, brooms and high pressure water jets) to expose the worst case fracture conditions for observation, measure-

The rock type consisted predominantly of a hard, grey, coarse-grained mica schist (Straits Schist). The rock surface ranged from hard and smooth to rough, irregular and blocky. Chemical weathering plus freeze wedging, root activity and glacial plucking have been the dominant processes acting to open the fractures. Fracture widths ranged from 0.25 to 6 in., but in every case these openings narrowed to hairline cracks within a few feet of the surface. Prior to cleaning, these cracks were filled with compact clay soil. Thus, it was determined that shallow surface weathering processes were the only plausible mechanism for producing open fractures. There was no evidence of contaminant migration in any fractures.

FINDINGS

Based on the information obtained from these various investigations, the geologic and hydrogeologic characteristics of the site were established. The goal was to determine the leachate migration pathway and define groundwater conditions adjacent to the fill. The information provides a basis for understanding potential environmental impacts associated with the flandfill.

Site Geology

The results of the investigations demonstrated that the bedrock underlying the site is part of the resistant Straits Schist, as described by Carr.[1] The orientation of the vast majority of fractures in the surface of the exposed bedrock are predominantly parallel to the foliation. Fractures did not show evidence of displacement, indicating that faults or shear zones are not present. Fracture widths at the surface were as much as 6 in., but quickly tapered to hairline cracks. This is consistent with observations made by Ellis,[2] who found that in artificial cuts, such as a quarry, joints that may be open 0.5 in. at the surface were found to be very tight at 25 ft below the surface. Rock coring near the landfill also confirmed this observation.

Weathering of the exposed bedrock surfaces was largely dependent on the minerology and degree of fracturing. In areas where the bedrock was predominantly composed of feldspar and quartz crystals, there was little physical and chemical weathering; in exposures where the rock was fractured and composed of muscovite and biotite, weathering was more extensive. However, though root penetration and frost wedging had enlarged fractures at the surface, they quickly narrowed, indicating that the effect of weathering is limited to the upper 5 or 10 ft of the rock.

As shown in Figures 6 and 7, the bedrock surface forms an elongated ridge orientated in a north-south direction under the eastern portion of the landfill. Bedrock is at or near the surface to the east of the fill, and till underlies the western portion.

A wedge-shaped body of low permeability glacial till overlies the bedrock in the western portion of the site (Fig. 7). The till consists of a dense, gray, clayey, fine to medium sand with trace fine gravel to coarse sand. Gneissic and schistose boulders are scattered throughout the unit. Test pit and test borings indicate that till textural composition is relatively consistent with depth.

Site Hydrogeology

The site consists of three distinct water bearing units; the bedrock system, the till and the landfill body. Water in the bedrock is confined to secondary openings such as joints or other fractures. Therefore, fractures within the rock become the predominant stor-
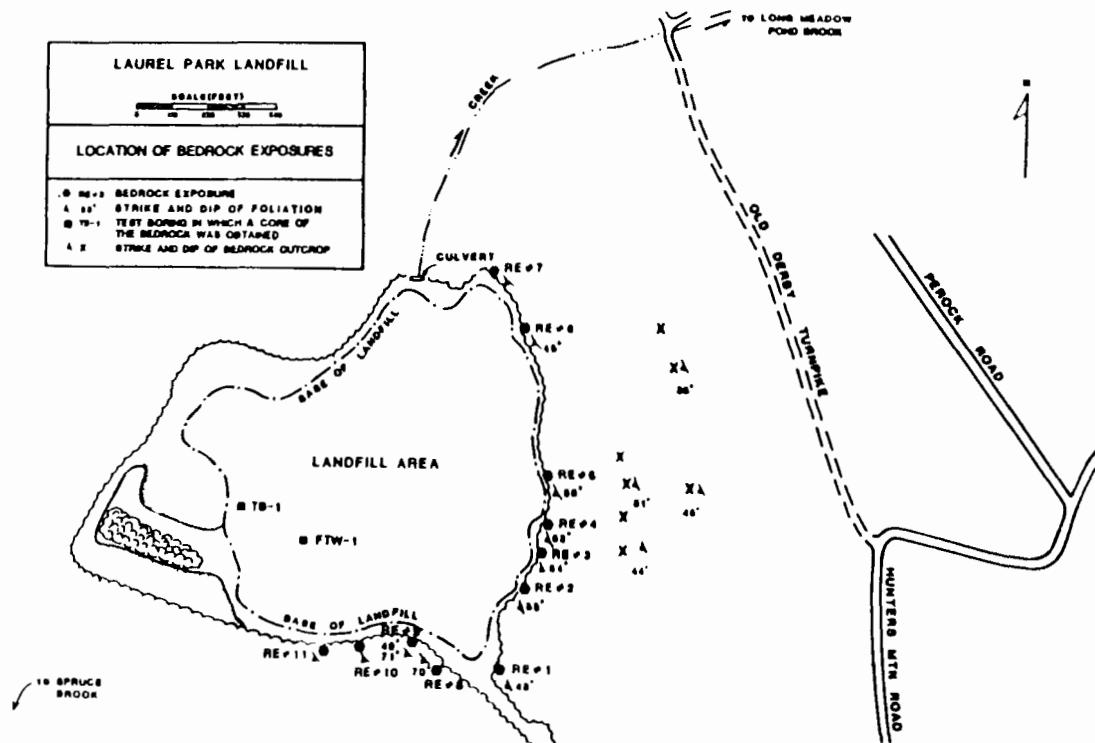
Figure 5
Location of Bedrock Exposures

age area for water, and the continuity, frequency, width and degree of interconnection among the fractures dictate the overall water bearing properties of the rock mass. As mentioned previously, field observation and previous studies[2, 3] support the authors' contention that the width and interconnectness of fractures decrease rapidly with depth.

Schist, in particular, is susceptible to fracture closure. Because it is less competent than other metamorphic rock, schist responds to regional stresses by minute bending or slipping along foliation planes, similar to a relaxation that is distributed internally throughout the rock mass. Although fractures develop in schist, they are likely to be nearly closed and discontinuous and, therefore, poor conduits for water.[3] Also, the physical and chemical mechanisms for widening fractures are all concentrated at the surface and have little effect on the width of fractures 10 ft or more below the surface.

Based on literature research, it was concluded that if any interconnected fractures existed in the bedrock, they would be within 100 ft of the surface; between 100 and 200 ft there may be a few thin fractures, but these are limited in extent and interconnectivity. Below 200 ft, fractures would be essentially nonexistent. Based on the intense investigation of the bedrock within the immediate vicinity of the landfill, it was concluded that the vast majority of water in the bedrock actually flows within 10 ft of the surface.

Because flow in the bedrock is restricted to the upper few feet, topography and bedrock surface configuration have the dominant control on groundwater flow direction. Thus, the shallow groundwater flow divides would be expected to closely approximate surface water drainage divides and bedrock highs. A groundwater divide underlies the landfill slightly east of well FW-4. East of the divide, due to the very steep topography, groundwater flow is discharged to the surface or moves at the soil/bedrock interface. West of the divides, in addition to topographic controls, groundwater flow is also influenced by the northwest-southeast fracture orientation. The combined effect is to direct groundwater flow to discharge to the creek at the north end of the site.

The till is a compact poorly sorted material of fine-grained clay size particles resulting in a low permeability. Laboratory permeability measurements from bulk samples taken at the site ranged from 6.8 x 10^{-6} to 1.5 x 1^{-5} cm/sec and overaged 4.0 x 10^{-6} cm/

sec. Calculations indicate that lateral seepage, using a permeability of 10^{-6} cm/sec, porosity of 10% and a hydraulic gradient of 0.1, would be approximately 1 ft/yr. This value of the hydraulic gradient indicates that water held in the till is subject to very little lateral or vertical movement and that the till can be considered as a saturated body, rather than an aquifer.

Although not a natural geologic deposit, the landfill can be considered as part of the site hydrogeology because it is in direct communication with the underlying glacial till and bedrock and contains a saturated zone with definite lateral flow. However, the evidence indicates that the leachate, rather than moving downward, is flowing horizontally and exiting the landfill in seeps around the base. The leachate level in the fill is unusually low when compared to fill relief, indicating thorough lateral drainage of the landfill body.

In summation, it has been determined from this investigation that, while the landfill is in direct communication with the underlying till and bedrock, practically no leachate is entering the underlying geologic materials. This is because the underlying formations have very low permeabilities and, as such, water held in the fractures of the bedrock or the interstices of the till is subject to very limited lateral or verticle movement. In essence, these two units can be considered as saturated but with very little groundwater movement, and they are acting as a natural liner. Leachate in the landfill flows over this stagnant water layer and exits out the base of the fill.

The leachate layer mounds in an arch similar to the curve of the bedrock surface under the fill, which results on a high point slightly east of well FW-4. This causes a driving head that parallels the bedrock or till surface, forcing the leachate to flow along the bedrock/fill or till/fill interface. The leachate level is parallel to the till/fill interface and several seeps on the north face of the landfill connect with this level. The seeps at this end of the landfill were observed to have a continuous discharge, indicating that this is a preferred flow direction for the leachate.

Groundwater and Leachate Quality

Between June and Nov., 1982, residential supply wells surrounding the site were sampled by the Conn. Dept. of Health Services (DOHS). Additionally, on Jan. 18 and 19, 1983, the leachate from
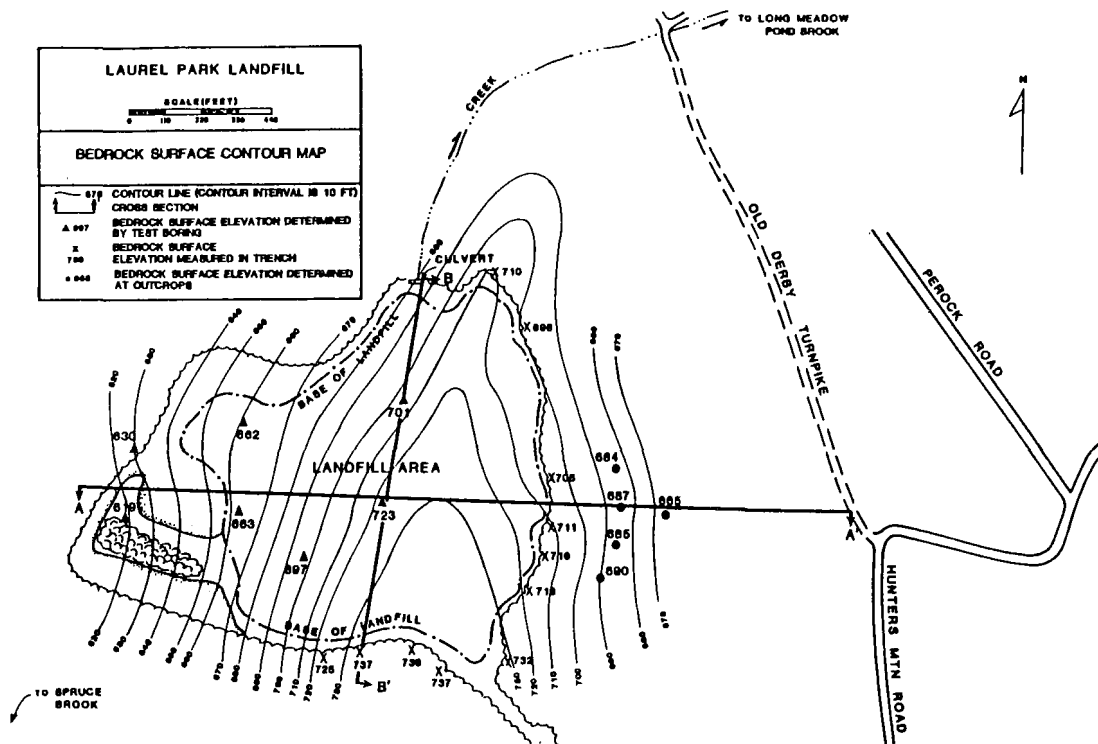
Figure 6
Bedrock Surface Contour Map
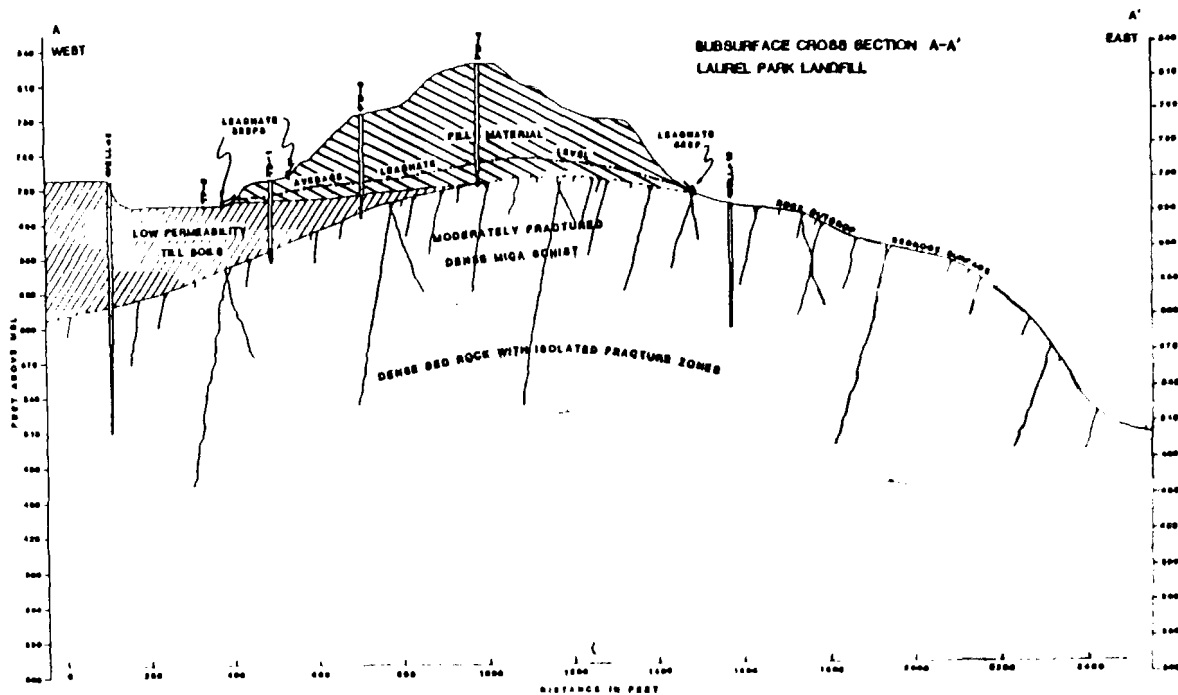
Figure 7
Subsurface Cross Section A-A' Laurel Park Landfill
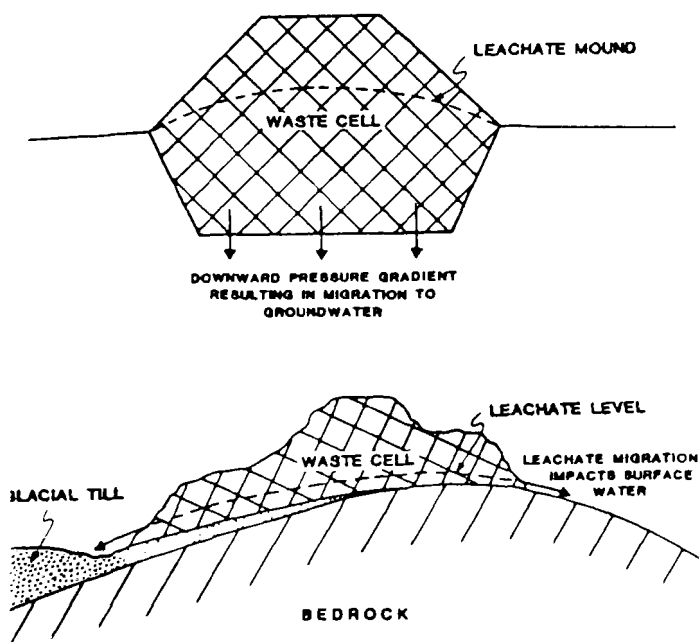
Figure 8
Comparison of Typical Landfill and Laurel Park Landfill

Figure 9
Laurel Park Landfill
East Trench Toe Drain

three landfill wells (FW-2, FW-3 and FW-4) was sampled and analyzed. The results of the leachate analysis showed a wide variety of volatile organic compounds, some at fairly high concentrations. If leachate from the landfill was migrating through the bedrock awuifer to these wells, then it is logical to assume that after 20 yr of landfill operation and potential migration, that some of the compounds would have been detected in the residential wells. However, of the 36 wells samples by DOHS, only one well showed compounds found in the leachate and this only at trace levels.

In order to fully evaluate the potential for migration, a complete groundwater monitoring system is presently being installed at the

landfill. It will consist of wells at various depths on the east, south and north sides. Rock core is also being obtained during this effort to further evaluate the characteristics of the bedrock aquifer.

CONCLUSIONS

Geologic and hydrogeologic information obtained from this site investigation indicates that the eastern portion of the Laurel Park Landfill lies directly on the bedrock surface or a thin till covering, while the western portion is separated from the bedrock by a wedge of low permeability glacial fill. This information, accompanied by data revealing that the bedrock and till are at their maximum elevations beneath the landfill and slope downward to the east, west and north, indicates that the most likely pathway of leachate migration will be in the horizontal direction, with leachate exiting the fill at or near the base of the slope and draining off the mountain via the surface water drainage.

As shown by Figure 8, this situation is different than typical landfill conditions, in which groundwater impacts from leachate migration can be expected due to a build-up of a leachate head in the waste cell causing a downward pressure gradient that results in eventual downward migration. If the underlying formations are significantly permeable, then the leachate will enter the groundwater system. However, at the Laurel Park Landfill, the underlying formations are very poorly permeable and there is no deep component of groundwater flow (400 to 500 ft) as postulated by past reports. Therefore, it is extremely unlikely that a pathway exists between the landfill and the downgradient water supply wells, and there is no conclusive evidence of groundwater contamination from the landfill.

Because the majority of leachate runs directly off the site into the surface drainage system, an effective leachate collection system is feasible. A network of toe drains and rock trenches has been installed adjacent to the base of the landfill to collect the near surface groundwater and leachate and convey it by gravity flow to the Naugatuck Wastewater Treatment Plant for treatment and disposal.

The leachate collection system consists of two separate systems, an East and a West Trench Drain. The East Trench Drain consists of approximately 1,750 ft of 4 in. diameter ABS pipe placed within a gravel envelope (Fig. 9). The perforated leachate collection pipe and gravel envelope have been installed in a trench 10 ft^2 in cross-section and cut through rock on the south and east sides of Huntington Hill. The West Toe Drain consists of approximately 2,400 ft of 4 in. diameter ABS pipe placed in a gravel envelope in the till along the south, west and north sides of the landfill. The installed drain system should provide a highly effective mechanism controlling leachate excape from the landfill.

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EVALUATION OF "SUPERFUND" SITES FOR CONTROL OF LEACHATE AND CONTAMINANT MIGRATION

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INTRODUCTION

Engineering-Science, Incorporated has been involved in studies relating to the management of hazardous wastes at sites throughout the United States for a number of years. Assessment studies, remedial alternative studies, treatment process studies and implementation of remedial action plans have been included as a part of these hazardous waste management studies.

The purpose of this paper is to share some experiences that personnel at Engineering-Science have had in studies relating to leachate control and control of migrating groundwater that has been contaminated.

LEACHATE CONTROL AT TAYLOR ROAD LANDFILL

Taylor Road Landfill is an unlined 42.5-acre municipally owned landfill that was operated by Hillsborough County, Florida from 1976 to 1980. The landfill received approximately 800 tons/day of municipal solid waste during its operational life.[1] The landfill was closed in February, 1980 and a cover consisting generally of clayey sands and sand was placed over the solid waste.

The USEPA sampled groundwater at and near the landfill in October, 1979. Volatile organic compounds were present in the water around the landfill. A subsequent study[4] sponsored by the County confirmed the presence of contaminants in the groundwater and outlined the approximate extent of the contamination.

Mechanisms whereby the landfill would contaminate the groundwater include:

- Leachate produced by the groundwater levels rising above the base of the landfill
- Leachate produced by rainwater percolating downward through the landfill
- Liquid waste discharging from containers buried in the landfill

One or more of these mechanisms could be contributing to contamination of groundwater in the area of the landfill.

This study began in November, 1981 with a geophysical investigation to help define the base of the landfill. The primary mechanism for groundwater contamination was initially believed to result from groundwater contacting the base of the landfill during periods of high groundwater levels.

The results of the geophysical investigation, together with an evaluation of groundwater level trends in the area of the landfill, indicated that the base of the landfill was probably above the general water table. However, it was determined that periodically perched water in the area of the landfill could contribute to the generation of leachate at the landfill.

The condition of the landfill cover observed during the geophysical investigation suggested that the cover might not be adequate and that downward percolation of surface water might be a significant contributor to the production of leachate. Standing water was observed in placed on the landfill cover and in the surrounding drainage ditches, and large cracks were observed in the cover in other places.

In October, 1982, a subsequent study to evaluate the effectiveness of the landfill cover was conducted.

Purpose and Scope

The purpose of this study was to determine how effectively the existing landfill cover and drainage prevented percolation of water to the waste materials.

The scope of work included a field investigation at the Taylor Road landfill, computing a water balance for the cover overlying the landfill and evaluating the probable hydrologic impacts on percolation of upgrading the cover and surrounding drainage.

Site Description

The landfill is located in eastern Hillsborough County, Florida and is approximately 10 miles east of Tampa (Fig. 1).

The landfill is situated on top of a north-south trending ridge that ranges between elevations of 80 ft and 120 ft above mean sea level. This ridge probably reflects a high area in the underlying limestone bedrock.

The regional topography is karst in nature. Numerous sinkholes can be identified near the landfill study on the USGS Thonotosassa and Brandon topographic maps.

Field Data Collection Program

The objective of this investigation was to define the physical characteristics of the cover overlying the Taylor Road landfill. The field data-collection program included infiltration tests of the landfill cover, determination of cover thickness and sampling the cover and drainage ditches for laboratory analyses of selected soil properties.

Sixteen infiltration tests were conducted on the Taylor Road landfill. The test sites were positioned in a rectangular pattern to obtain a uniform distribution of observations over the area (Fig. 2).

The infiltration tests were conducted in general conformance with the American Society for Testing Materials (ASTM) standard test for measuring infiltration rate of soils in the field using a double-ring infiltrometer.[1] Two cylinders, one inside the other, were driven into the ground. The outer 36-in. diameter cylinder was driven 6 in. deep. The inner 12-in. diameter cylinder was driven 2
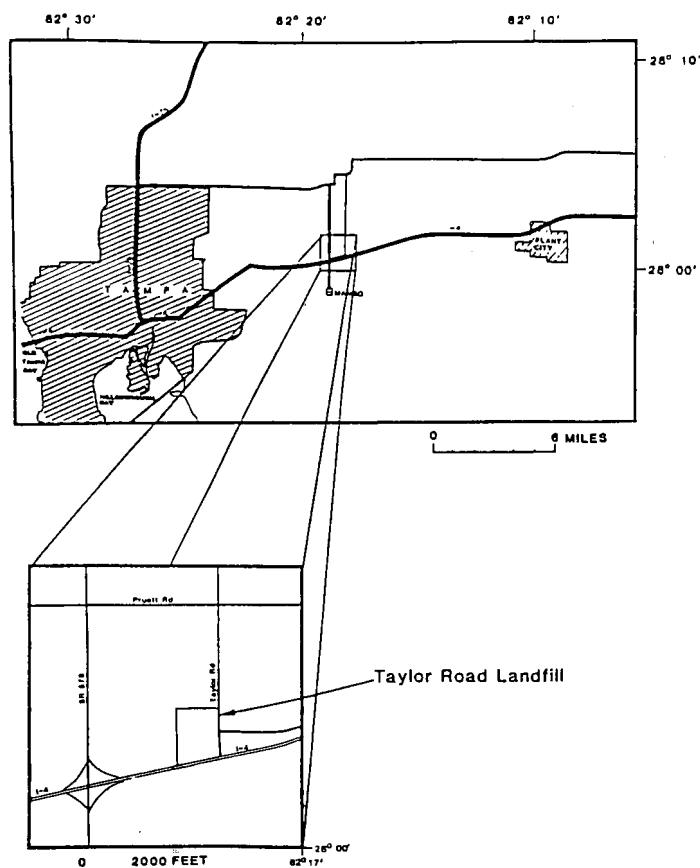
Figure 1
Location of Study Area

EXPLANATION

4,1 • INFILTRATION TEST AND SOIL SAMPLING SITE

D3 ■ SOIL SAMPLING SITE ONLY

0   500 FEET
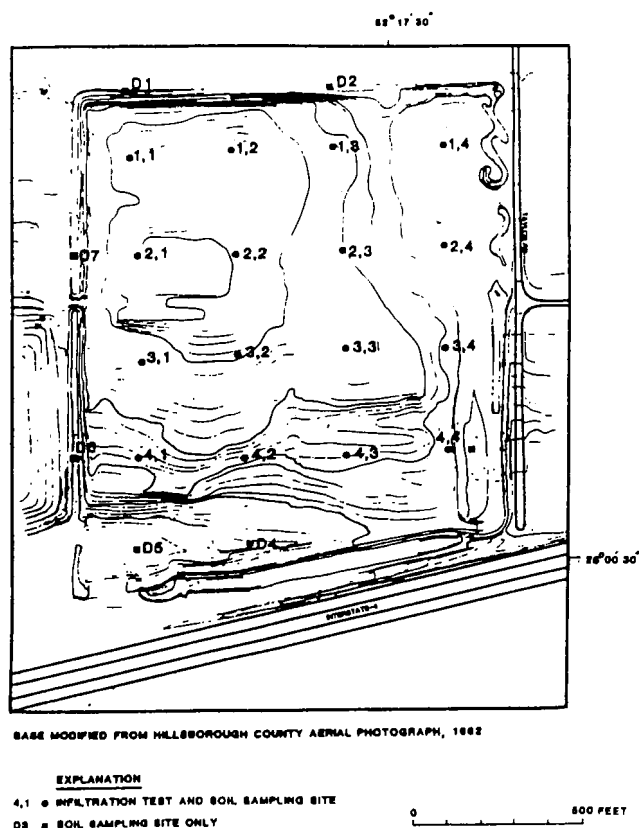
Figure 2
Location of Hydrologic Data Sites

in. deep. A constant water depth of 6 in. was maintained within the cylinders during testing by adding water at regular intervals. Thirteen infiltration tests were 8 hr in length. Three 24-hr tests were conducted.

The vertical hydraulic conductivity of the landfill cover at its surface varies from about 5×10^{-5} cm/sec to less than 5×10^{-6} cm/sec. This conductivity range is derived from the 8-hr infiltration tests by assuming that the steady-state infiltration rate at a site, or vertical hydraulic conductivity, will be one-half the measured 8-hr rate. This assumption is reasonable based on the results of the 24-hr tests that were conducted coupled with the trends observed in infiltration rates during the tests.

Soil samples from selected depths at each infiltration test site and from test sites along drainage ditches adjacent to the landfill were subjected to laboratory analysis of vertical hydraulic conductivity and grain size. The samples for testing were collected using Shelby tubes. Vertical hydraulic conductivity was measured using a constant head permeameter. Grain size analyses were conducted in general conformance with ASTM standards.[2,3] The vertical hydraulic conductivities for soil samples from five sites at the Taylor Road landfill were too great to measure. The soils at these sites consisted mostly of sands. The vertical hydraulic conductivities for soil samples from the other sites varied between 1.2×10^{-5} and 2.0×10^{-9} cm/sec. These samples consisted mostly of clayey sand. The vertical hydraulic conductivities for soil samples from six of the seven drainage ditch sites consisted mostly of sand and were too great to measure with a constant head permeameter.

The thickness and composition of the cover overlying the landfill was determined at each of the infiltration sites by test borings. The maximum observed cover thickness at the landfill is greater than 48 in. The minimum observed cover thickness at the landfill is 8 in. The cover is composed of clayey sands, sandy clays and sand.

Interpretation of Findings

The probable hydrologic impacts of upgrading the landfill cover and drainage ditches were investigated. The effectiveness of reducing percolation through the landfill cover by increasing the average cover thickness and decreasing the average cover vertical hydraulic conductivity was studied. Also, the impacts on percolation of runoff to the water table by improving the drainage ditches at the landfill were addressed.

Average annual percolation was computed for the Taylor Road landfill cover based on a monthly soil water balance. Average monthly infiltration into the landfill cover was determined from a surface water balance for the cover (Table 1). Infiltration was computed as the difference between average monthly precipitation and average monthly runoff. Average precipitation at the landfill for each month was assumed to be equivalent to average monthly precipitation recorded at Plant City, Florida for the period 1951 to 1979. Average monthly runoff was computed by computing average annual runoff at the landfill using the Soil Conservation Service Curve Number method and distributing this runoff in accordance with the percentage of average annual rainfall that occurs each month. The results of the infiltration tests on the landfill cover were used to aid in these computations.

Monthly soil moisture changes in the cover and monthly evapotranspiration from the cover were computed using methods outlined by the USEPA.[4] Soil moisture changes are based on monthly changes in infiltration and potential evapotranspiration. Monthly evapotranspiration was computed based on monthly infiltration rates, monthly potential evapotranspiration rates and computed changes in monthly soil moisture.

Percolation through the landfill cover is negligible for average rainfall (Table 2). Infiltration into the cover is not great enough to overcome evapotranspiration demands and deficiencies in soil moisture storage.

Percolation was computed for above normal rainfall conditions. Yearly rainfall was assumed to be 140% of normal rainfall, or 74.92 in., for the simulated wet condition. Yearly rainfall totals in excess of that simulated here should occur about one year in five on

Table 1
Surface Water Balance for Taylor Road Landfill
Cover for Normal Precipitation

Month	Precipitation (in.)	Runoff (in.)	Infiltration (in.)
January	2.53	1.94	0.59
February	3.33	2.55	0.78
March	3.75	2.87	0.88
April	2.09	1.60	0.49
May	4.05	3.10	0.95
June	7.16	5.48	1.68
July	8.05	6.15	1.90
August	8.65	6.61	2.04
September	6.81	5.21	1.60
October	2.89	2.21	0.68
November	1.93	1.48	0.45
December	2.28	1.74	0.54
TOTALS	53.52	40.94	12.58

Table 2
Soil Water Balance for Taylor Road Landfill
Cover for Normal Precipitation

Month	Infiltration (in.)	Soil Moisture Change (in.)	Evapotrans-piration (in.)	Percolation (in.)
January	1.94	0.61	1.33	0
February	2.55	1.16	1.39	0
March	2.87	0.41	2.46	0
April	1.60	−1.20	2.80	0
May	3.10	−0.71	3.81	0
June	5.48	−0.16	5.64	0
July	6.15	−0.12	6.27	0
August	6.61	−0.04	6.65	0
September	5.21	−0.04	5.25	0
October	2.21	−0.19	2.40	0
November	1.48	0.00	1.48	0
December	1.74	0.28	1.46	0
TOTALS	40.94	0	40.94	0

Table 3
Soil Water Balance for Taylor Road Landfill
Cover for Above Normal Precipitation

Month	Infiltration (in.)	Soil Moisture Change (in.)	Evapotrans-piration (in.)	Percolation (in.)
January	2.71	0	1.33	1.38
February	3.57	0	1.39	2.18
March	4.02	0	2.46	1.56
April	2.24	−1.22	3.46	0
May	4.34	−0.51	4.85	0
June	7.67	1.38	6.29	0
July	8.61	0.35	6.92	1.34
August	9.25	0	6.73	2.52
September	7.29	0	5.71	1.58
October	3.10	−0.74	3.84	0
November	2.07	−0.08	2.15	0
December	2.43	0.82	1.46	0.15
TOTALS	57.30	0	46.59	10.71

the average.[7] Average monthly evapotranspiration conditions were assumed for the computations.

Annual percolation through the Taylor Road landfill cover for the simulated wet condition was 10.71 in. (Table 3). Percolation occurred during the winter months and again during the summer months. The corresponding average annual volume of water percolating through the cover to the solid waste was approximately 12,000,000 gal.

The hydrologic impact of increasing the average cover thickness at the Taylor Road landfill by 24 in. was investigated for above normal precipitation conditions. The simulated annual rainfall was 74.92 in.

Annual percolation through the landfill cover for the simulated wet condition and added soil cover was 10.46 in. This percolation rate is not substantially different from the 10.71 in. of annual percolation computed without the added cover thickness. Increasing the average cover thickness by 24 in. does not substantially reduce percolation through the cover during wet periods.

Decreasing the average vertical hydraulic conductivity of the landfill cover would substantially decrease the amount of infiltration into the cover and, hence, percolation to the solid waste during wet periods (Table 4). The maximum amount of annual infiltration to the solid waste would only be limited by the amount of rainfall that occurred if the hydraulic conductivity of the landfill cover was 1×10^{-5} cm/sec. The maximum annual infiltration would be limited to approximately 12 in. of rainfall or 14,000,000 gal by reducing the average hydraulic conductivity of the landfill cover to 1×10^{-6} cm/sec and 1 in. or 1,000,000 gal by reducing the average hydraulic conductivity of the landfill cover to 1×10^{-6} cm/sec and 1 in. or 1,000,000 gal by reducing the average hydraulic conductivity of the landfill cover to 1×10^{-7} cm/sec.

It appears reasonable, based on the above analysis, that a vertical hydraulic conductivity of 1×10^{-7} cm/sec or less for the landfill cover would substantially reduce or eliminate percolation through the cover. The current landfill cover has an average vertical hydraulic conductivity somewhere between 1×10^{-5} and 1×10^{-6} cm/sec, which could potentially allow large quantities of percolation during wet periods.

Percolation of significant quantities of water to the water table in the vicinity of the landfill could be eliminated or significantly reduced by improving surface drainage at the landfill.

Table 4
Effect of Soil Cover Vertical Hydraulic
Conductivity on Infiltration

Vertical Hydraulic Conductivity (cm/sec)	Maximum Annual Infiltration (in.)	(million gals)
10^{-5}	124	143
10^{-6}	12.4	14.3
10^{-7}	1.2	1.4

The average annual volume of runoff that percolates to the water table in ponded areas along the east and south drainage ditches (Fig. 3) is equivalent to approximately 11,000,000 gal/yr or 21 gal/min. Some of the runoff that flows to the north and west drainage ditches also percolates to the water table. The material at the base of the drainage ditches is generally sand which would allow rapid percolation of water.

Regrading the east and south drainage ditches to eliminate the ponded areas and to direct runoff away from the landfill would suppress most of percolation that is currently occurring from these drainage ditches. Lining all of the draining ditches with a clay or other relatively impermeable material would reduce or eliminate
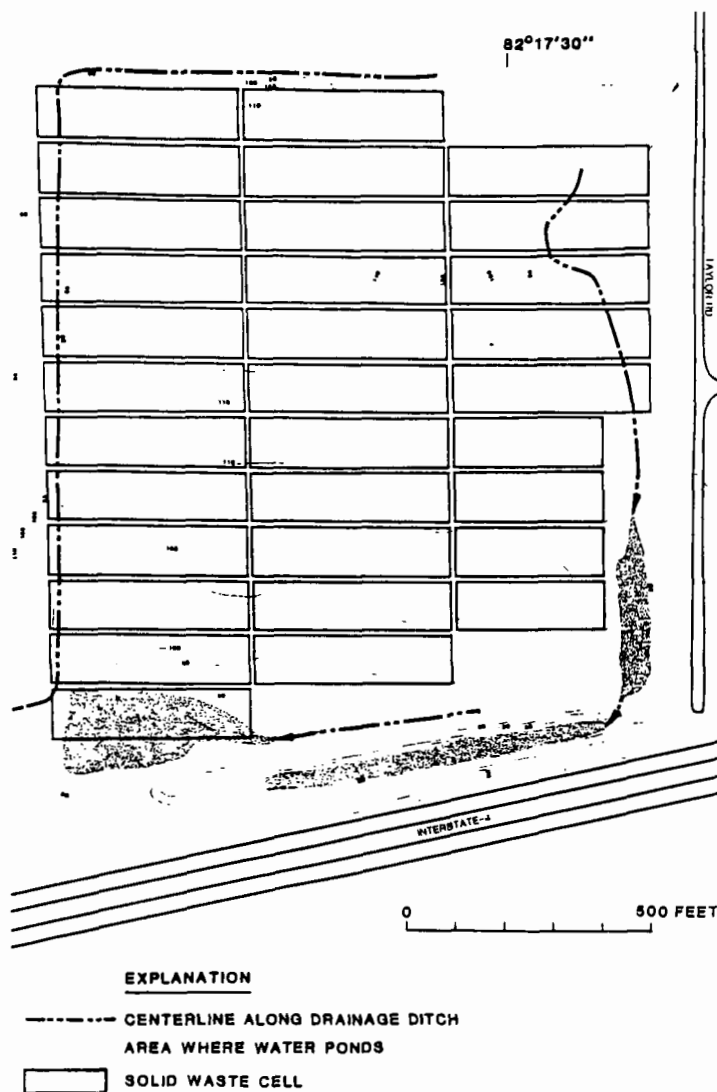
Figure 3
Relation Between Surface Drainage and Solid Waste Cells

percolation through the bottom of the drainage ditches during
runoff events.

Remedial Actions

Measures are currently being taken by Hillsborough County to
upgrade the landfill cover and drainage ditches surrounding the
landfill. A minimum 24-in. thickness of cover is being placed over
the landfill in areas where the cover is less than 24 in. in thickness.
A minimum 6-in. thick soil layer whose permeability is less than 1
$\times$ 10^{-7} cm/sec is being placed over the cover in areas where testing
has indicated that the permeability of the existing cover was inade-
quate. Also, the drainage ditches are being upgraded to reduce per-
colation of water, and ponding is being eliminated in the southeast
and south areas of the landfill.

CONTROL OF CONTAMINATED GROUNDWATER MIGRATION

A client is required to perform certain work at his plant site in
South Carolina as a result of a recent settlement reached between
the client and the South Carolina Department of Health and En-
vironmental Control (DHEC). Part of this work involves im-
plementing a groundwater recovery and treatment program for
contaminated groundwater.

Purpose and Scope

The purpose of this study was to identify the extent of ground-
water contamination in the vicinity of the plant site and to design
and implement a groundwater recovery and treatment system.

The scope of work included field data collection and laboratory
analysis. Field data collection efforts included a geophysical survey
to aid in defining the extent of groundwater contamination, an ex-
ploration drilling program to aid in determining the hydrogeology
of the area, base flow measurements along streams near the plant
site to define surface water-groundwater relationships and sam-
pling water from wells and from streams for testing in the
laboratory. Groundwater and surface water were analyzed for
selected chemical constituents that would be indicators of con-
tamination.

Field Data Collection Program

The objective of the field data collection program was to collect
sufficient data for developing a groundwater recovery and treat-
ment system. The study area included the plant site and the area
between two streams in the vicinity of the plant site.

Water was drawn from 25 of the 27 wells in the study area (Fig.
4). Wells located on the plant site were sampled Sept. 7, 1983. Four
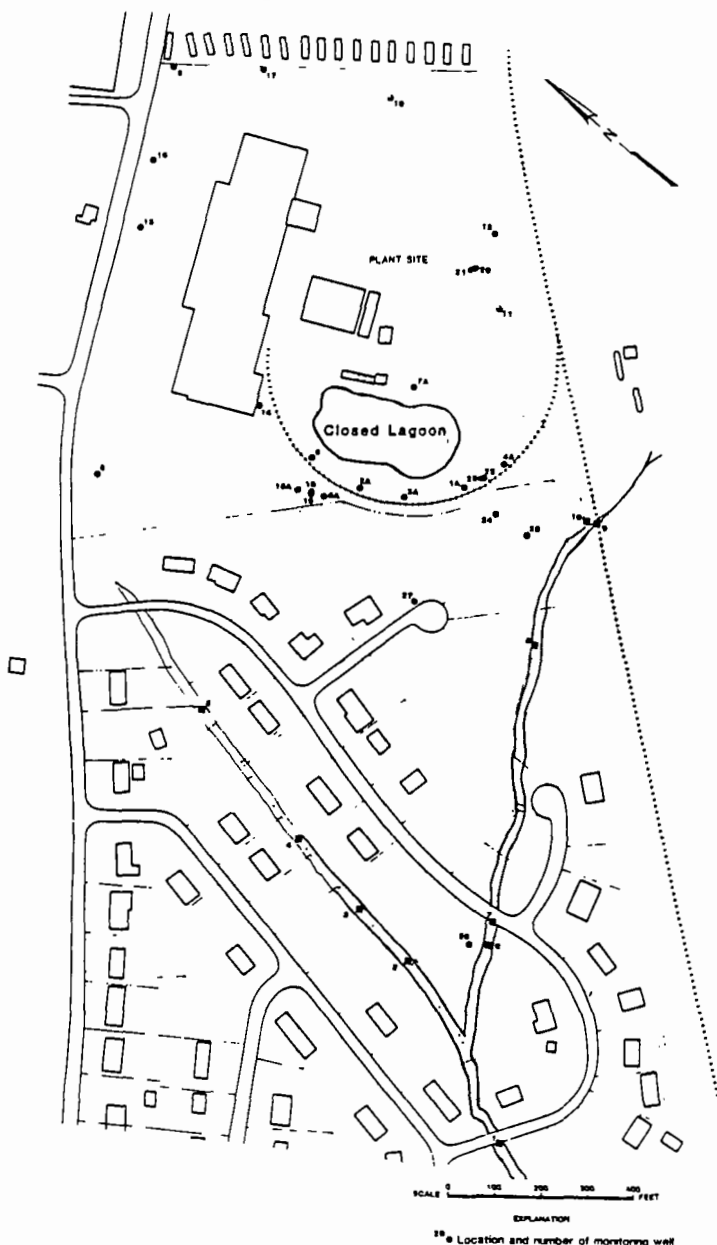
Figure 4
Location of Monitoring Sites

wells off the plant site (wells 24, 25, 26 and 27) were sampled on Jan. 6, 1984. These four wells had not been constructed when the September sampling was done. The water samples collected on Sept. 7 were analyzed for dissolved sulfates, total and dissolved lead and total dissolved solids. Specific conductance, pH and temperature were measured in the field at the time of sampling. The water samples collected on Jan. 6 were analyzed for total sulfates, total and dissolved lead, total and dissolved chromium and specific conductance. Temperature and pH were measured in the field at the time of sampling. Sampling, storage and preservation were performed in accordance with procedures recommended by the USEPA.[9]

Streamflow measurements were made and water samples were collected at 10 locations along the streams (Fig. 4). These data were collected on Nov. 30. The water samples were analyzed for total sulfates and dissolved lead. Specific conductance, pH and temperature were measured in the field. Sampling, storage and preservation were performed in accordance with procedures recommended by the USEPA.[9]

Chemical analyses of the water samples were performed using procedures recommended by the USEPA.[10] The dissolved and total metals were measured by preparing the samples according to general metals digestion procedures and then measuring the constituent metal content using atomic absorption spectroscopy. Sulfates were measured using the turbidimetric method. The dissolved solids (TDS) in the water samples were measured as the total filtered residue dried at 180 °C. The results of the water analyses are given in Tables 5 and 6.

Depth to water measurements for computing groundwater elevations were taken at each well at the time of sampling. The depth to water measurements were taken with a steel tape. The water-level elevation in each well was determined by subtracting the measured depth to water from the reference point elevation on the top of the well casing from which the measurement was made. Groundwater elevations at the time of sampling are summarized in Table 5.

An earth electrical resistivity survey was performed using a Bison 2350B resistivity unit on, and in the vicinity of the plant site. In this investigation, voltage drop was measured between two potential electrodes placed in the earth resulting from an applied current through two other electrodes located outside, but in line with, the potential electrodes. The standard Wenner electrode array was used during resistivity profiling. Measurements were made with electrode spacings of 10, 30, 60 and 100 ft.

Three wells were constructed southwest of the plant site under the supervision of Engineering-Science personnel (Fig. 4). These wells were for use in hydrogeologic studies. The wells were constructed between Nov. 1 and Nov. 14. Wells numbered 24 and 25 were located in the vicinity of existing wells 1A, 22 and 23. Well 25 was placed at approximately the same distance southwest of well 24 as wells 1A, 22 and 23 are located northeast of well 24. In this manner, well 24 could be used as the pumping well during an aquifer pumping test and wells 1A, 22, 23 and 25 would be available for observation of drawdowns during testing. Well 26 was located approximately 1000 ft southwest of well 24 near the confluence of two streams that are hydraulically downgradient from the plant site. This well was drilled to verify the existence of contamination identified in that area by the geophysical survey. All three wells were also for use in gathering lithologic data and sampling groundwater.

An additional well was constructed southwest of the plant site by a local well driller under contract to the client. This well, well 27, was drilled during the last week in October. The well is approximately 250 ft west of well 24 (Fig. 4).

A 24-hr aquifer pumping test of well 24 was performed on Nov. 19-20, 1983. Pumping began at 10:30 AM Eastern Standard Time on Nov. 19 and lasted until 10:45 AM on Nov. 20. The pumping rate was 4.17 gal/min. The pumped water was discharged to the

Table 5
Summary of Groundwater Analyses

Well No.	Measurement Date	Dissolved Sulfate (mg/l)	Total Sulfate (mg/l)	Total Lead (mg/l)	Dissolved Lead (mg/l)	Dissolved Chromium (mg/l)	Total Chromium (mg/l)	Total Dissolved Solids (mg/l)	Specific Conductance (umhos)	pH (std. units)	Temp. (°C)	Groundwater Elevation (MSL)
	1983											
1A	Sept. 7	810	-	0.34	0.32			1,380	1,600	3.4	17.0	993.23
3A	Sept. 7	600		.97	.25	-		1,180	1,420	4.0	914.15	
4A	Sept. 7	52	-	.18	.04			127	89	4.1	16.6	993.03
5A	Sept. 7	750		.37	.15	-		1,260	1,230	3.7	16.4	996.67
6	Sept. 7	390		.37	.15			722	720	3.9	17.7	993.88
7A	Sept. 7	440		.56	.41	-		760	864	4.1	17.2	1000.92
8	Sept. 7	24		.18	.16	-		130	73	4.5	20.4	1011.34
9	Sept. 7	23		1.3	.02	-		89	35	4.4	17.3	1023.93
10	Sept. 7	1		.78	.13	-	-	<1	49	4.6	17.4	1314.06
11	Sept. 7	3		.45	.20	-	-	48	13	4.6	19.7	1006.16
12	Sept. 7	1		.24	.18	-	-	61	33	4.6	17.3	1307.34
13	Sept. 7	2		.36	.21	-	-	94	22	4.4	17.6	1018.65
14	Sept. 7	1660		.63	.51	-	-	3,370	2,910	3.4	13.9	1009.08
15A	Sept. 7	280		1.4	.39	-	-	555	608	4.2	17.3	
16	Sept. 7	4		.22	.14			57	43	4.4	17.3	1373.38
17	Sept. 7	3		.12	.02			83	59	4.3	16.3	1021.73
18	Sept. 7	220		.28	.24	-		459	500	4.4	16.7	996.91
19	Sept. 7	280		.26	.19			542	647	4.6	16.5	996.30
20	Sept. 7					-		-				1006.95
21	Sept. 7	2		.14	.13		-	110	37	5.6	18.1	1006.90
22	Sept. 7	640		.35	.21			1,170	1,160	3.7	16.5	991.87
23	Sept. 7	589		.16	.15		-	1,140	1,160	5.5	16.5	992.53
	1984											
24	Jan. 6	1,830		.20	.14	0.09	0.09	3,400		3.7	17.1	
25	Jan. 6		444	.14	.12	<.05	.06	1,120		3.8	17.3	
26	Jan. 6		2,700	.24	.15	<.05	.08	4,850		4.6	17.1	
27	Jan. 6		4,650	.20	.19	.11	.15	8,100		4.1	17.1	

Table 6
Summary of Surface Water Analyses

Site No.	Measurement Date (1983)	Total Sulfate (mg/l)	Dissolved Lead (mg/l)	Specific Conductance (umhos)	pH (std. units)	Flow (gpm)
1	Nov. 30	368	0.21	753	4.3	
2	Nov. 30	332	0.11	578	4.2	41.6
3	Nov. 30	251	0.19	507	4.4	27.1
4	Nov. 30	50	0.26	110	4.8	31.2
5	Nov. 30	15	0.13	52	5.3	12.0
6	Nov. 30	559	0.37	1000	4.2	50.4
7	Nov. 30	598	0.34	1010	4.8	30.0
8	Nov. 30	415	0.36	817	4.4	25.0
9	Nov. 30	293	0.12	39	5.1	6.5
10	Nov. 30					0.0

plant wastewater pretreatment facility for treatment and discharge to the city sewage lines. Wells 1A, 22, 23 and 25 were used as observation wells.

Well construction details for the pumped well and the observation wells varied between wells. Wells 24 and 25 each have approximately 34 ft of screen located in the upper one-half of the unconsolidated geologic deposits. Well 1A has 10 ft of screen located at the water table of the unconsolidated deposits, well 22 has a 5-ft screened interval located in the center portion of these deposits and well 23 is completed as an open hole at the top of competent bedrock. A geologic cross-section showing the screen settings for the wells used in the test is given in Figure 5.
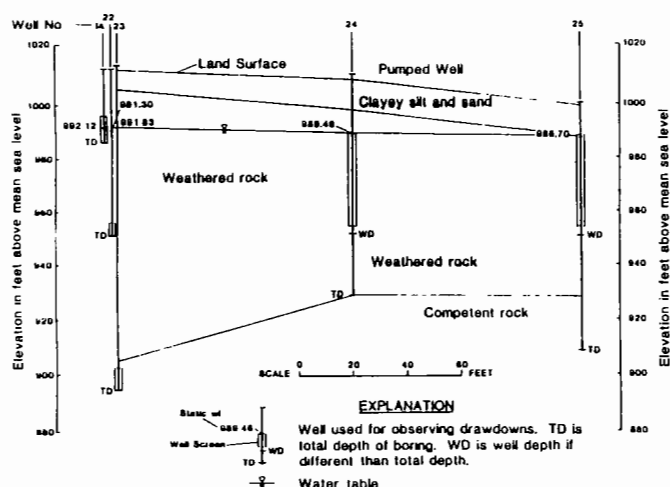
Figure 5
Well Arrangement Used for Aquifer Pumping Test

Water levels were measured in the pumped well and each of the observation wells. Water-level declines were observed in each of the wells during pumping. The maximum water-level decline in the pumped well was 12.7 ft. Maximum water-level declines in the observation wells ranged between 0.18 and 0.53 ft.

The water-level data for the pumped well and the observation wells were used to compute the hydraulic properties of the unconsolidated deposits in the vicinity of the wells. The Theis nonequilibrium formula[5] and water-level data for the observation wells were used to compute transmissivity and storage coefficient. The

modified nonequilibrium formula[5] also was used to compute transmissivity and storage coefficient. Hydraulic conductivity for the unconsolidated deposits was estimated based on the computed transmissivity and estimated effective saturated thickness at each well. The results of the analyses are given in Table 7.

Average hydraulic properties for the unconsolidated deposits were estimated by averaging the results from the individual wells. The average hydraulic conductivity for these deposits is approximately 49.5 gal/day/ft^2. The average storage coefficient is about 0.0040. These numbers were computed by averaging the results for wells 1A, 22 and 23 to represent the hydraulic properties upgradient from the pumped well, averaging the results for well 25 to represent the hydraulic properties downgradient from the pumped well and using these averages along with the computed hydraulic properties at the pumped well to compute overall average hydraulic properties for the test.

The storage coefficient computed using data from well 1A appeared to be anomalously high and was not used in the computations for the average value. This relatively high storage coefficient
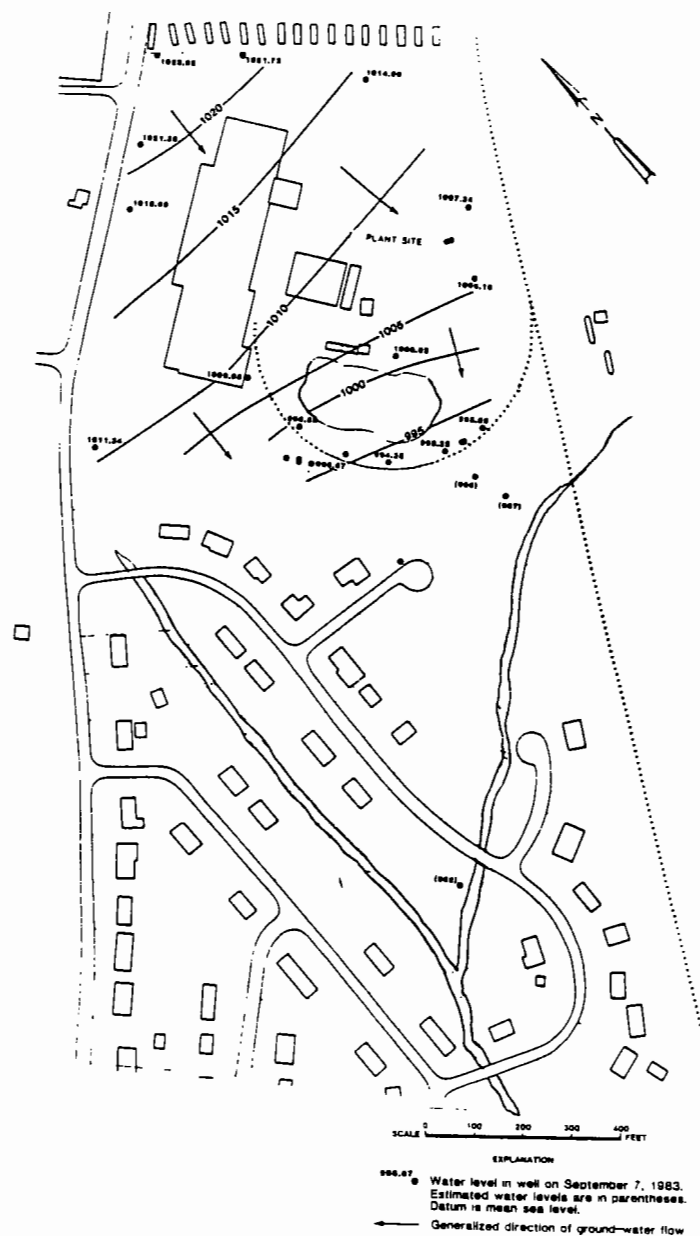
Figure 6
Water Table and Direction of Groundwater Movement

Table 7
Aquifer Pumping Test Summary

Well No.	Transmissivity (gpd/ft)	Storage Coefficient	Saturated Thickness (feet)	Hydraulic Conductivity (gpd/ft^2)	Method of Analysis*	Remarks
1A	_,990	.036	86	34.9	N	Storage coefficient not used in average
	3,800	.026		44.2	M	Storage coefficient not used in average
22	3,410	.0025	86	39.7	N	
	3,340	.0023		38.8	M	
23	3,980	.0021	86	46.3	N	
	2,900	.0046		33.7	M	
Avg	3,400	.0029	86	39.5		Average hydraulic properties of unconsolidated deposits upgradient from pumped well.
24	1,380	--	38	36.3	M	Average hydraulic properties of unconsolidated deposits at the pumped well.
25	4,340	.0053	60	72.3	N	
	4,400	.0050		73.3	M	
Avg	4,370	.0052	60	72.8		Average hydraulic properties of unconsolidated deposits down-gradient from pumped well.
AVERAGE FOR TEST		.0040		49.5		

N = Nonequilibrium Formula

M = Modified Nonequilibrium Formula

resulted because of the long delay in the response of the water level in well 1A to pumping. It is probable that the storage coefficient at the water-table surface is higher than the storage coefficient averaged over the depth of the unconsolidated materials.

Interpretation of Findings

The results of the field data collection program were used to characterize the hydrology of the study area. The shallow subsurface setting, groundwater flow directions and the extent of groundwater contamination were described.

The subsurface in the study area consists of competent bedrock overlain by unconsolidated residual material or saprolite, that has been weathered from the bedrock. The competent bedrock is predominantly a mica schist. The unconsolidated residual material generally consists of a silty clay or silty sand overlain by residual soil composed mostly of clay. The thickness of the unconsolidated deposits is 80 to 100 ft at the plant site. These deposits are about 35 ft thick near the confluence of the streams. Approximately the upper 10 ft of the unconsolidated deposits are residual soil.

Groundwater flow directions were determined from the shape of the water table (Fig. 6) Water table contours were drawn using the elevation of water levels in the sampling wells. Groundwater flows at approximately right angles to these contours from areas of higher head to areas of lower head.

Groundwater flow in the area of the plant site is to the southwest. Groundwater flows from the northeast, moves under the plant site and discharges to the streams southwest of the plant.

Groundwater sampling, together with the results of the geophysical survey, indicates that groundwater contamination exists southwest of the plant site between the area of the streams (Fig. 7).

Also, contaminated groundwater is discharging to the streams. Measurements of stream water quality in the streams verified that contaminated groundwater is discharging to these streams.

Remedial Actions

A groundwater recovery system was designed with the constraint that all recovery wells would be placed on property owned by the client (Fig. 8). The results of the hydrogeologic characterization indicated that contaminated groundwater coming from the plant site could be intercepted and streamflow water quality could be improved by placing wells only on this property. Also, long delays generally associated with negotiating easements for use of other property would be avoided.

The volume of contaminated water moving away from the area of the plant site is approximately 40 gal/min. This water will be intercepted by wells in order to eliminate off-site contamination of groundwater and the discharge of contaminated groundwater to the streams. The flow rate was estimated based on the water table gradient in the vicinity of the plant south property boundary and the physical properties of the unconsolidated deposits determined from the aquifer pumping test.

Seven wells located downgradient from the plant site should be adequate to intercept the volume of contaminated groundwater coming from the site. Five wells could be placed on lots 47, 48 and 49 southwest of the plant site to intercept contaminated groundwater in this area, and two wells could be placed southwest of the main plant building and near the plant property boundary to intercept contaminated groundwater in that area (Fig. 8). The pumping rate from each well would need to be about 6 gal/min to assure that all of the contaminated water is intercepted.

One well placed on lot 62 and another well placed on lot 63 would aid in removing contaminated water from the groundwater reservoir and would prevent further discharge to streams of contaminated water in this area. These wells would be limited in their pumping rate to 2 to 3 gal/min because of the limited thickness of unconsolidated material in this area.

CONCLUSIONS

In this paper, the author has presented case histories involving various aspects relating to the management of water quality of hazardous waste sites. One case study involved an evaluation of remedial measures for leachate control at a large municipal landfill. A second case study focused on assessing the extent of groundwater contamination at a manufacturing plant site and implementing a remedial action plan for alleviating the contamination.
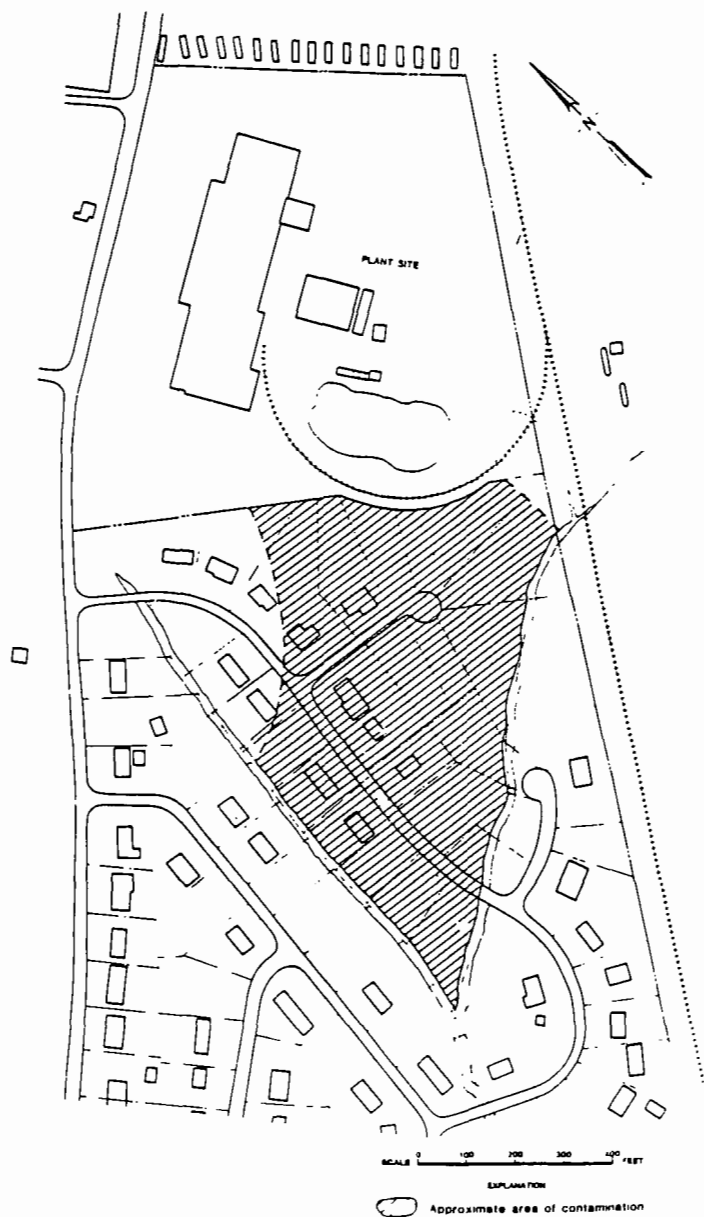
Figure 7
Approximate Area of Offsite Groundwater Contamination
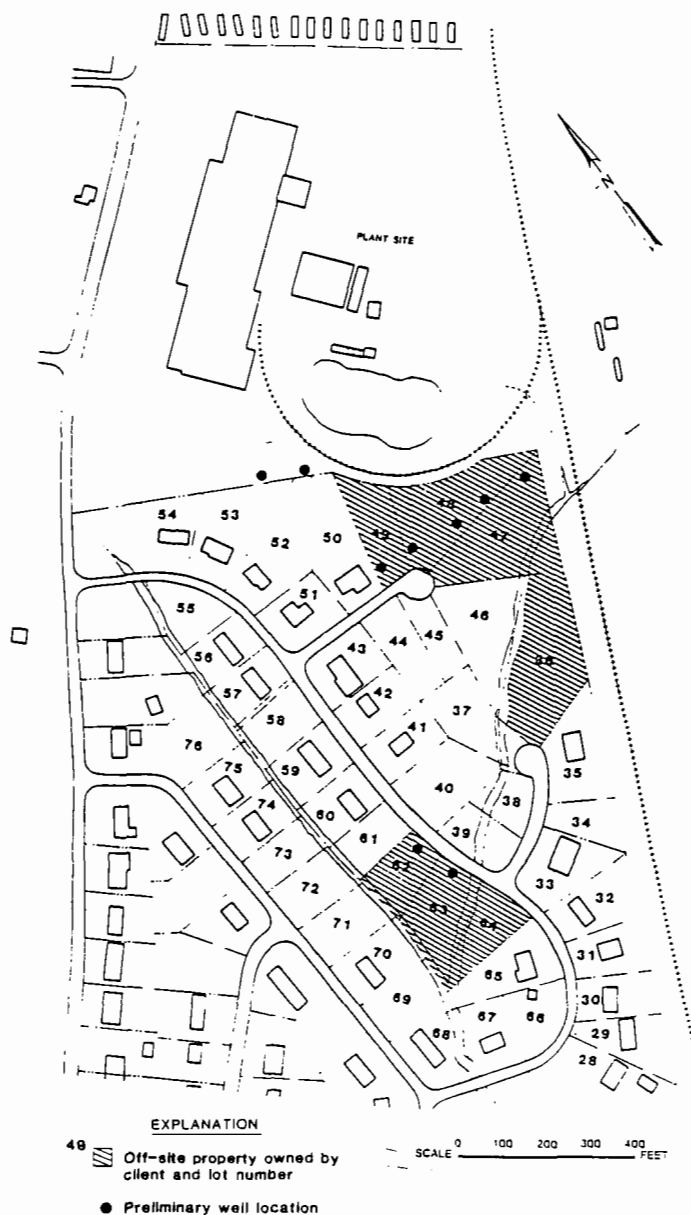
Figure 8
Preliminary Well Locations

ACKNOWLEDGEMENT

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LABORATORY INVESTIGATION OF PHYSICAL PROPERTIES OF FLEXIBLE MEMBRANE LINERS (FML)

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TEST METHODS

•Water Absorption ASTM D 471
 "Effects of Liquids on Rubber Property"
•Dimensional Stability ASTM D 1204
 "Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperatures"
•Puncture Resistance FTMS 101B-2031
 U.S. Federal Test 101B Method 2031
•Tensile Strength ASTM D 412 Die C
 "Rubber Properties in Tension"
•Elongation ASTM D 412
 "Rubber Properties in Tension"
•Brittleness Temperature ASTM D 746
 "Brittleness Temperature of Plastics Elastomers by Impact"
•Tear Resistance ASTM D 624 Die C
 "Tear Resistance of Rubber"
•*Water Vapor Permeability ASTM E 96 Procedure BW*
 "Water Vapor Transmission of Materials in Sheet Form"
•Breaking Strength ASTM D 751 Grab Method
 "Tested Coated Fabrics"
•Tearing Strength ASTM D 751 Tongue Tear Method
 "Testing Coated Fabrics"

Figure 1
Nonreinforced Water Absorption

TESTING

Water Absorption

Membrane specimens were immersed in distilled water according to ASTM D 471. Aging conditions were 7 days at 70 °C, and change in volume and change in mass after exposure were measured. The results of this testing are shown in Figures 1 and 2. All types of membranes increased in mass and volume with butyl rubber exhibiting the least effect and thermoplastic CPE exhibiting the highest increase in mass and volume.

Dimensional Stability

Membrane specimens were carefully measured for the length and width dimensions (machine and transverse directions, respectively). The specimens were then placed in an air-circulating oven for 7 days at 100 °C.

According to ASTM D 1204, after the aging period, the specimens were then remeasured and the percent changes were recorded. The results of this testing are shown in Figure 3. Butyl rubber exhibited the least average dimensional change, and thermoplastic CPE exhibited the greatest average dimensional change. All fabric reinforced membranes tested had less than 2% shrinkage.

Figure 2
Reinforced Water Absorption
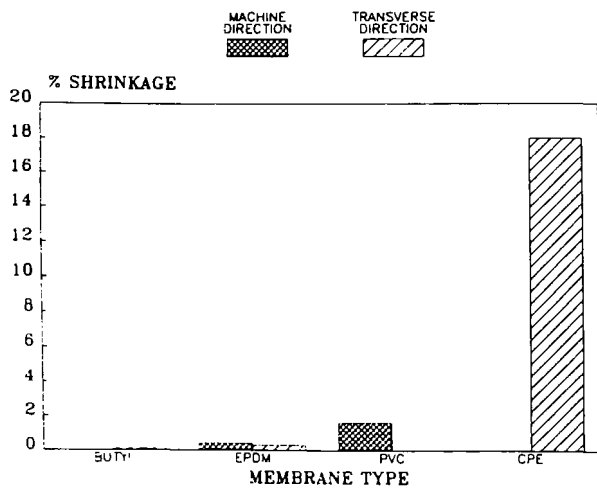
Figure 3
Nonreinforced Dimensional Stability
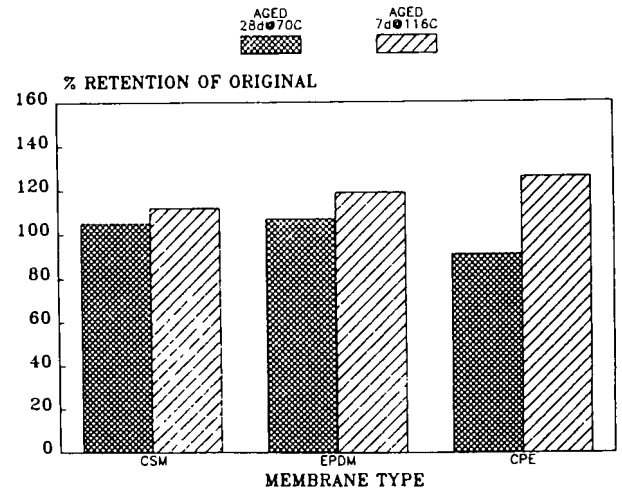
Figure 6
Reinforced Breaking Strength
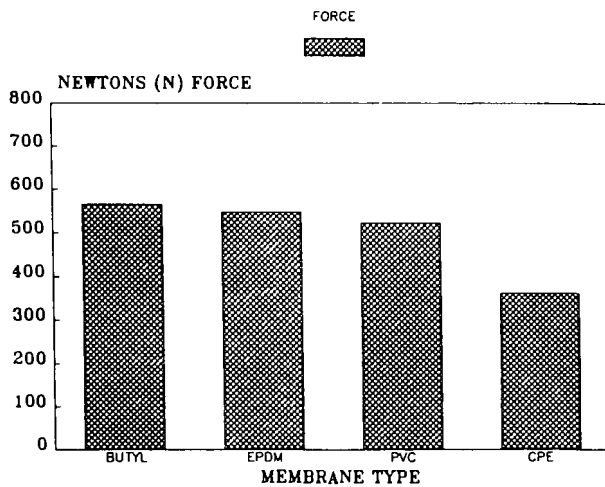
Figure 4
Nonreinforced Puncture Resistance
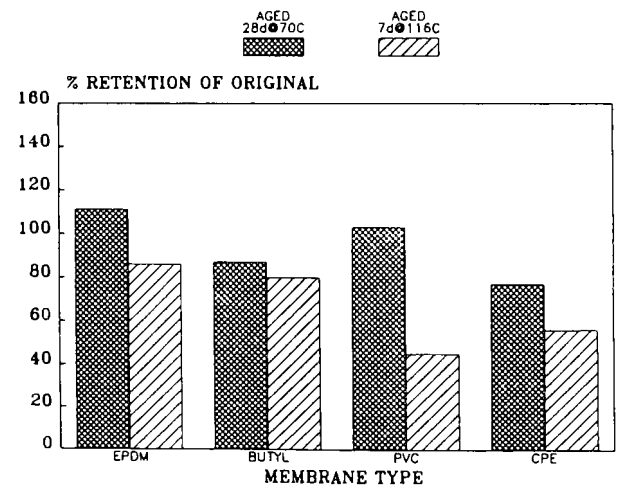
Figure 7
Nonreinforced Elongation
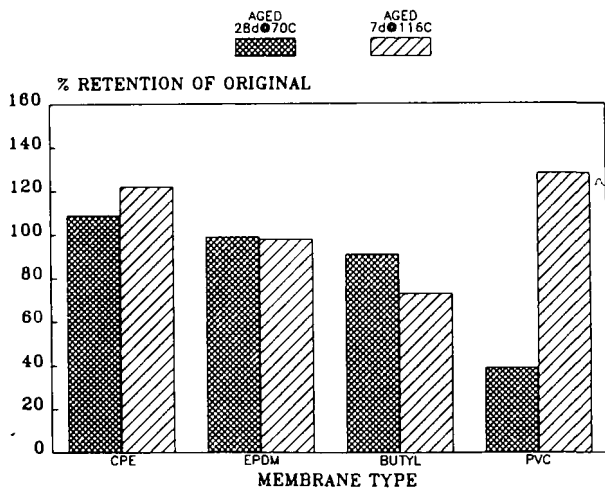
Figure 5
Nonreinforced Tensile Strength
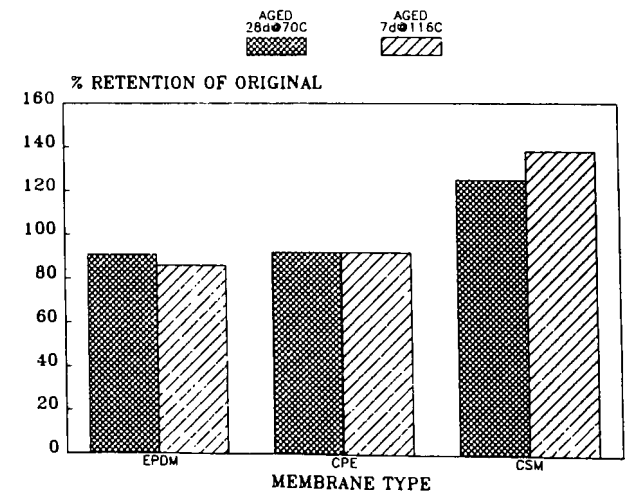
Figure 8
Reinforced Elongation (Fabric)

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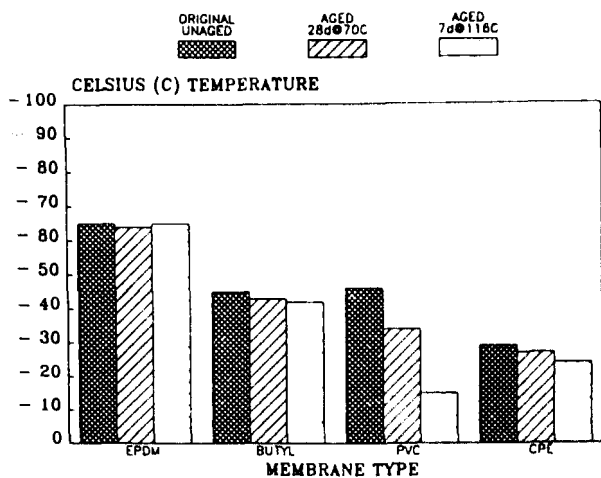
Figure 9
Nonreinforced Brittleness Temperature
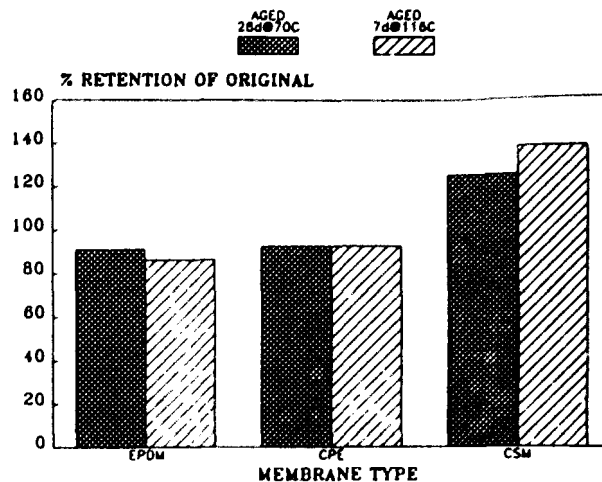
Figure 12
Reinforced Tearing Strength
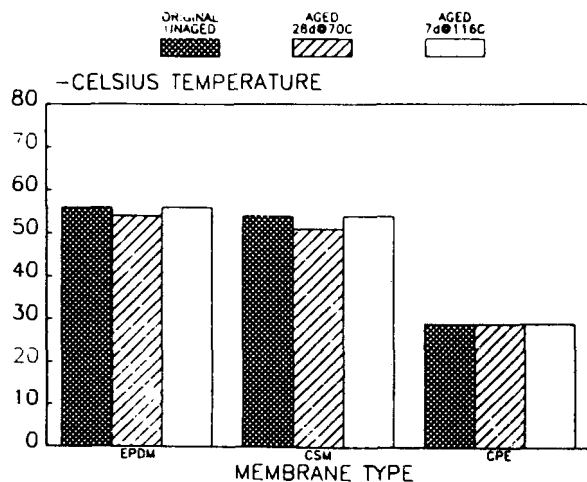
Figure 10
Reinforced Brittleness Temperature
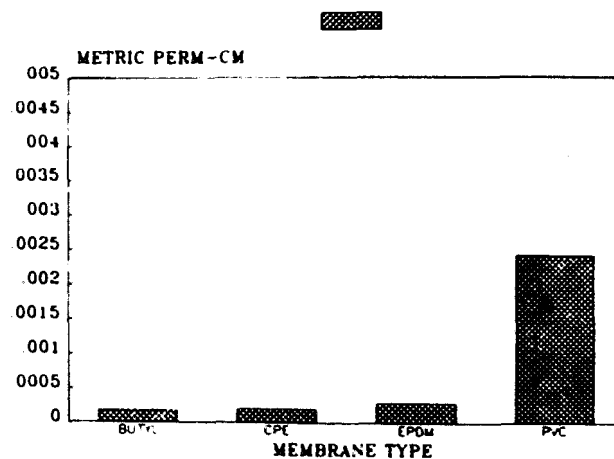
Figure 13
Nonreinforced Water Vapor Permeability
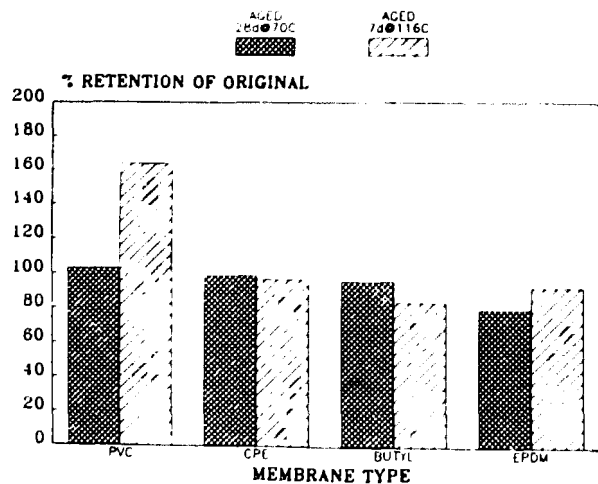
Figure 11
Nonreinforced Tear Resistance
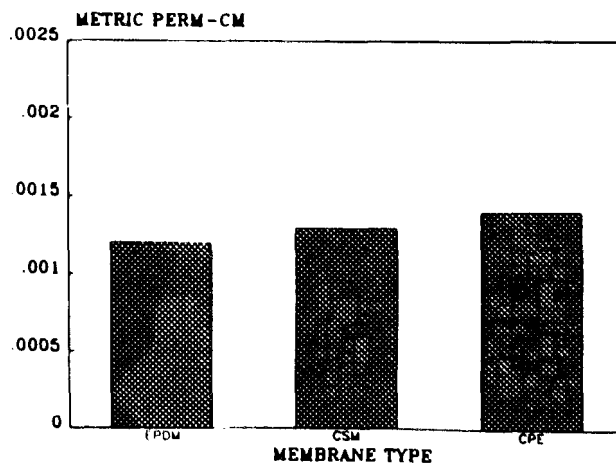
Figure 14
Reinforced Water Vapor Permeability

Puncture Resistance

Membrane specimens were tested for puncture resistance according to United States Federal Test 101B Method 2031. The results of this testing are shown in Figure 4. All membranes showed good puncture resistance with butyl rubber (1.562 mm.) exhibiting the best puncture resistance. Puncture resistance which is dependent on membrane thickness should be kept in mind when comparing these results. Data for fabric reinforced membranes is incomplete.

Elongation

Membrane specimens were tested for elongation retention after aging conditions of 7 days at 116 °C and 28 days at 70 °C according to SSTM D 412 or D 751. The results of this testing are shown in Figures 7 and 8. The aging conditions of 7 days at 116 °C were generally more severe than those of 28 days at 70 °C.

Tensile Strength/Breaking Strength

Membrane specimens were tested for tensile/breaking strength retention after aging conditions of 7 days at 116 °C and 28 days at 70 °C according to ASTM D 412 Die C or ASTM D 751. The results of this testing are shown in Figures 5 and 6. All membranes showed good retention of tensile/breaking strength after aging for both 7 days at 116 °C and 28 days at 70 °C except thermoplastic PVC which exhibited the worst tensile strength retention after 28 days at 70 °C.

Brittleness Temperature

Membrane specimens were tested for low temperature brittleness according to ASTM D 746. Low temperature brittleness was also determined after heat aging of 7 days at 116 °C and 28 days at 70 °C. The results of this testing are shown in Figures 9 and 10. EPDM and butyl rubbers and thermoplastic CPE and CSM exhibited good retention of brittle point. However, thermoplastic PVC exhibited the greatest effect of heat aging for brittleness temperature.

Tear Resistance/Tearing Strength

Membrane specimens were tested for tear resistance/tearing strength retention according to ASTM D 624 Die C and ASTM D 751 tongue tear. Tear resistance retention was also determined after heat aging of 7 days at 116 °C and 28 days at 70 °C. The results of this testing are shown in Figures 11 and 12. Thermoplastic PVC and CSM increased in tear resistance after heat aging, and the other membranes exhibited good retention of this property.

Water Vapor Permeability

Membrane specimens were tested for water vapor permeability according to ASTM E96 Procedure BW. The results of this testing are shown in Figures 13 and 14. Butyl rubber exhibited the lowest permeability (lowest amount of water vapor passing through an area per unit of time) while thermoplastic PVC exhibited the highest permeability.

CEMENT BARRIERS

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INTRODUCTION

Since the early 1970s several hundred slurry trench cutoff walls have been constructed to serve as underground barriers to the horizontal flow of water and other fluids. A major application has been in pollution control including the containment of hazardous wastes.

One of the most commonly used slurry wall methods is the soil-bentonite (S-B) slurry trench. In this method, a bentonite-water slurry is introduced into the trench during excavation to provide side wall support. After the trench has been excavated to its required depth, a mixture of soil, bentonite and water is placed into the trench displacing the bentonite-water slurry. The excavated soil is used in the backfilling operation; however, if it contains an excessive amount of contaminated or undesirable material such as cobbles or clay lumps, a selected backfill material may be required.

At sites where wall strength is important, waste compatibility with an S-B slurry mixture may be questionable or space limitation for mixing the S-B backfill adjacent to the trench may be a problem. Alternative types of slurry walls are available. These include cement barriers such as cement-bentonite slurry trenches, plastic concrete and structural diaphragm walls.

In this paper, the authors describe the various types of cement barriers. Information is presented on physical properties such as strength, deformability, waste compatibility and permeability. The authors also describe design and construction procedures for four unique waste containment projects.

CEMENT-BENTONITE SLURRY TRENCHES

For the cement-bentonite (C-B) slurry trench method, cement is added to the bentonite-water slurry just prior to its introduction into the trench. In addition to serving as a stabilizing fluid to maintain an open trench during excavation, the C-B slurry forms the permanent cutoff wall. The addition of cement generally increases the cost of a C-B trench over a comparable S-B trench; however, there are some distinct advantages with the C-B method:[1]

- The C-B method is not dependent on availability or quality of soil for backfill.
- The C-B method is more suitable in trenching through weak soils where trench stability may be a concern. The C-B slurry begins to set within hours after excavation, thereby reducing the chance of failure.
- The C-B slurry sets up to a stiff claylike consistency. Trenches may be cut through the wall without sloughing. Construction traffic may cross the trench after a few days.
- The construction sequence is more flexible. The C-B method permits trench construction in sections to meet site constraints. It adapts to hilly surfaces where a step-type construction can be performed. With the S-B method, the long open trench necessary to accommodate the flat slope of the backfill normally requires trenching continuously in one direction at a constant elevation.
- With a C-B slurry trench, construction may proceed during subfreezing temperatures. With the S-B method, special precautions are required to keep the backfill from freezing.
- The width of a C-B trench is generally less than for an S-B trench. For the S-B method, the trench must be wide enough to permit free flow of the backfill material.
- With the C-B method, an area adjacent to the trench is not required for mixing, thus making it more suitable in projects with space limitations such as the crest of a dam. Also, cleanup is easier with the C-B method.

Permeability is one of the most important factors in slurry trench applications. Both laboratory and field tests indicate permeabilities of C-B slurry trenches approximately equal to 1 ft/yr (10^{-6} cm/sec).[1]

Since a C-B slurry trench is not intended to support bending moments or significant shear stresses, strength usually is not a primary consideration. The trench is designed to achieve a strength equivalent to that of the surrounding soil. However, in projects where slurry trenches are constructed through unstable materials such as peats and mine spoils, trench stability, especially during excavation, is a critical consideration. The cement-water ratio has a significant effect on the strength of the C-B slurry trench. Also, as with concrete, strength increases with age. The effects of both cement-water ratio and age on strength are shown in Figure 1a.

The deformability or compressibility of a slurry trench is important when considering its application at waste disposal sites or in seismic areas where displacements may occur. The slurry trench must be able to accommodate the displacements without cracking. A major factor affecting the deformability of C-B slurry trenches is strength. Laboratory tests indicate that higher strength results in a stiffer less deformable wall. However, even with uniaxial compressive strength of 50 psi, the C-B slurry exhibits a high strain capacity. The relationship between ultimate uniaxial compressive strength and triaxial strain at failure is shown in Figure 1b.
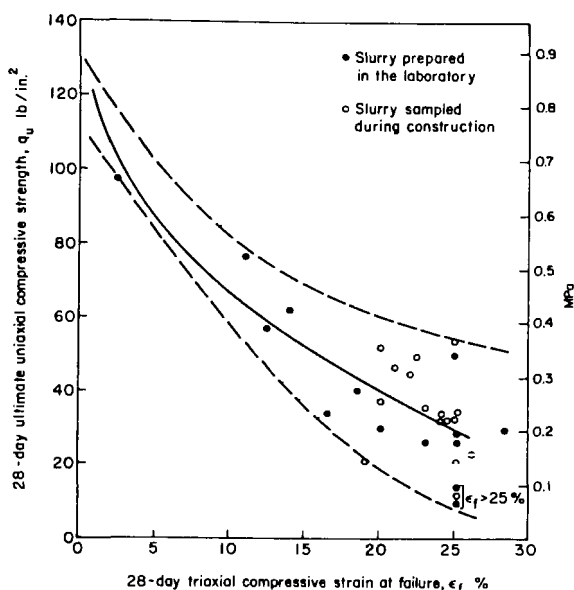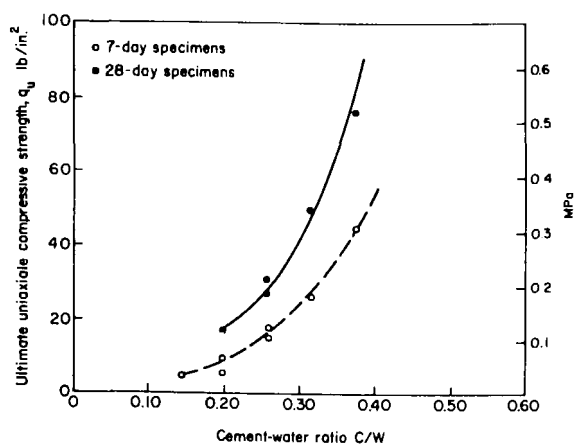
Figure 1
Typical Strength Deformation Test Results for Cement-Bentonite
Slurries

For applications that involve contaminated water or exposure to pollutants, it is important to determine the effect the waste has on the slurry trench. For example, acids will dissolve the cement components of a C-B slurry trench. Sulfates may also be harmful; however, the attack by sulfate soils or wastes may be reduced or prevented by using cement containing a low tricalcium aluminate (C_3A) content. In concrete design, Type II cement with a maximum C_3A content of 8% is used for moderate sulfate exposure (150 to 1500 ppm), and Type V with a maximum C_3A content of 5% is used for severe sulfate exposure (1500 to 10,000 ppm).

Stroudsburg

In October 1980, State of Pennsylvania officials observed black tarry globules emanating from the base of a dike along Brodhead Creek in Stroudsburg, Pennsylvania. The observed seepage was in the approximate location of an old coal gasification plant which generated coal tar as a by-product of the process.

Prior to its closure in 1940, the plant had disposed of coal tar residue through an injection well located in the northwestern section of the plant property. The well was constructed so that residuals were injected into a gravel alluvium layer about 20 ft below ground surface. Underlying this gravel layer was a layer of fine sand which provided an effective barrier to further downward migration.

In September 1981, the State presented its findings of an investigative study into the problem.[3] The study indicated that the contamination was confined generally to the gravel layer and had spread over an area approximately 8 acres. The report recommended construction of a slurry trench cutoff wall to contain the coal tar and prevent further migration into the streambed. Also recommended was the installation of a recovery well system to collect the coal tar wastes for removal.

Because of the nature and extent of contamination, the State applied for and received funds for remedial work under the Superfund program. These funds were appropriate on Nov. 9, 1981, making Stroudsburg the first site to receive Emergency Superfund monies.

Under USEPA supervision, compatibility testing was conducted to determine the most appropriate slurry wall composition. The decision to use a C-B mixture was based upon three factors: (1) the compatibility test results, (2) the lack of area for on-site mixing of an S-B backfill and (3) the unavailability of local clays for use in an S-B backfill.

The slurry mixture, which has a design permeability of 10^{-6} cm/sec, consisted of 133 lb of bentonite and 345 lb of cement per cubic yard of slurry. The original trench design included the use of a polyethylene liner placed within the trench for added impermeability. The length and weight of the material, however, caused problems during attempted installation and the material was never utilized.

Construction of the slurry trench began on Nov. 25, 1981. The completed trench is 648 ft long, 1 ft wide and 17 ft deep. It extends down through the contaminated gravel stratum and is keyed 2 ft into the underlying sand layer. The overall surface elevation of the trench is approximately 380 ft above sea level. The upstream end of the trench is tied into a sheet piling gate that is part of the existing flood dike. The downstream end is tied into an impermeable cement-bentonite grout curtain (Fig. 2). The curtain was constructed to form the final downstream segment because it was believed that trench excavation in proximity to the dike would have impaired the dike's integrity. The grout curtain was installed by pressure grouting through a series of vertical holes in the ground. The curtain is approximately 50 ft long.[4]

The trench was excavated with a backhoe along a narrow 11.5 ft wide working platform. During trenching operation, the contaminated material was separated and hauled by track-mounted bucket loader to a small on-site storage basin. Periodically, the stored material was loaded onto a sealed truck and transported to a disposal facility in Niagara Falls, New York.

The slurry trench was completed on Dec. 15, 1981, at which time drilling began for the grout curtain. The cement-bentonite grout curtain was completed within 7 days.
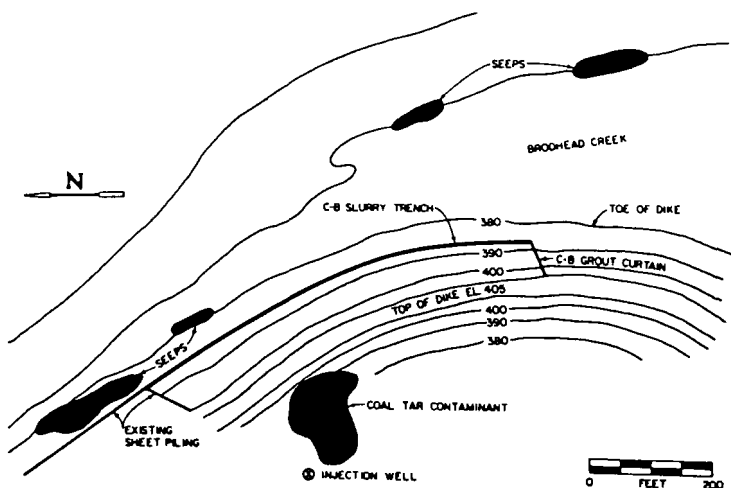
Figure 2
Extent of Contamination and Slurry Wall Location at Stroudsburg Site

JFK Bulk Fuel Tank Farm

Most slurry trenches constructed for containment purposes require a clay or rock layer underlying the site to provide an impervious stratum into which the trench can key. Petroleum products such as fuel oil do not mix with and are lighter than water. As a result, they will float on top of the groundwater table. In this case, it is not necessary to key the slurry trench into an impervious layer. The bottom of the trench may simply extend a reasonable depth below the minimum expected groundwater table.

In 1980, fuel oil was observed in an estuary channel adjacent to a major fuel tank farm at Kennedy Airport in New York City. The Port Authority of New York and New Jersey, the tank farm owner, determined that spills within the tank farm over the years had saturated the sandy soil and that oil was now draining into the channel.

The remedial action consisted of stabilizing the existing bank with fill and riprap and installing a slurry trench to intercept the leaking oil (Fig. 3). Because a peat layer exists beneath the site, the Port Authority specified the C-B slurry trench method over the S-B method. Since C-B slurry backfill has a lower unit weight than S-B backfill, less pressure would be exerted on the weak peat layer. Restricted site conditions also favored the use of the C-B method. Active high pressure fuel lines were buried as close as 3 ft to the trench, making an S-B backfill mixing operation over these pipes very risky. At several locations along the 4000 ft long slurry trench, piers supporting utility and fuel lines passed over the trench. Special care and equipment were required to excavate the trench in these areas (Fig. 4).
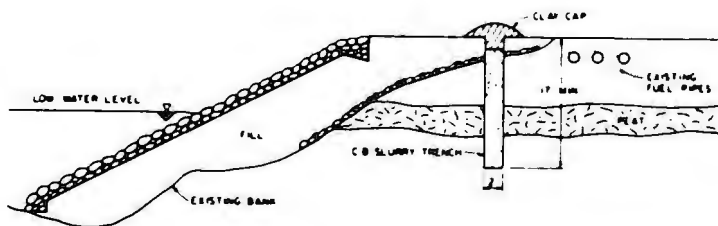
Figure 3
Typical Embankment Section After Remedial Work at Kennedy
Airport Fuel Tank Farm

Figure 4
Working in Confined Area with Backhoe and 9-Ton Clamshell

Laboratory tests were conducted to verify that the C-B slurry met specified requirements. Permeability values for the C-B slurry mixture having a cement-water ratio of 0.2 ranged from 6.6 ft/yr at 7 days to 2.6 ft/yr cm/sec at 31 days. The permeability tests were conducted at an isotropic effective stress of 0.50 ton/ft² using site water as the effluent. Unconfined compressive strengths ranged from 0.35 to 0.8 ton/ft² for 7-day cured specimens.[1]

As part of the remedial work, two 30,000 gal concrete retention tanks collect contaminated runoff and separate out the oil products. The oil is recycled to supply building heating fuel and fuel for fire training exercises at the airport.

PLASTIC CONCRETE WALL

In order to meet permit requirements for two new coal-fired units, Montana Power Co. had to meet clean air standards for a class one, pristine area. This was accomplished by Bechtel Corporation whose engineers designed and tested a new flue-gas scrubber system for the Colstrip Generating Station, Colstrip, Montana. The system uses a treated, hydrated dolomite lime to remove more than 91% of the sulfur dioxide. While meeting the Federal air standard for emissions, the system produces a side stream of about 100,000 tons a year of scrubber waste.

An effluent holding pond located approximately 4 miles east of the plant was designed to accept the scrubber waste. The perimeter of the pond was 16,536 ft long. To contain the waste, several possibilities were examined. A slurry cutoff wall was eventually chosen as the barrier method.

Contractor Option

Prospective contractors were prequalified and only those with proven ability were allowed to submit proposals for the work. The type of barrier and design was the contractor's option. One major requirement was that the wall be 2.5 ft wide and have a maximum permeability of 1 ft/yr.

The geology of the site consisted of several near horizontal horizons of tertiary sedimentary rocks assigned to the Fort Union Formation. This formation occurs as a series of interbedded, semiconsolidated to consolidated carbonaceous sandstone, siltstone and claystone with occasional coal beds.

Since there was little to no soil to be excavated and no locally available soils, the S-B method utilizing soil as backfill was considered the most expensive method. Also, because of the subsurface conditions, a considerable length of time would be required to excavate the trench to the specified depth. With the C-B method, this time delay would cause the C-B slurry mixture to set-up prior to reaching final depth. Set retarding agents could be used, but because of the variability in subsurface conditions an exact set time delay could not be established. Continually altering the mix to facilitate construction would be neither desirable nor acceptable.

The selected contractor, ICOS Corporation of America, proposed a plastic concrete wall 2.0 ft wide having a permeability of less than 1 ft/yr. This type of cutoff wall was determined to be the easiest and most economical. The method consisted of initially filling the excavation with a bentonite-water mixture to keep the side walls from collapsing. The bentonite-water slurry was then replaced with a tremie concrete. The economy of the plastic concrete method became apparent in the design of the concrete backfill. Since the project was in an area where fly ash is abundant and inexpensive, the backfill was designed using fly ash as a replacement for some of the cement.

Testing

Prior to construction, the concrete backfill was tested both for permeability and compatibility. The testing procedure required that backfill be permeated with water to establish a base permeability coefficient. Next, the specimen was to be permeated with the scrubber waste composition (Table 1). To determine the compatibility of concrete to the waste, two pore volumes of effluent were to be permeated and the results compared with the initial water testing.

Figure 5
Permeability of Plastic Concrete Backfill Permeated with
Scrubber Waste Solution

When permeated with water, the concrete specimen had the required permeability of 0.1 ft/hr. When the same specimen was permeated with the scrubber waste liquid, the permeability decreased significantly to less than 10^{-4} ft/yr (Fig. 5). This created a new problem. With permeability this low and getting lower with time, it was estimated it would take over 100 years to permeate one pore volume.

Table 1
Typical Scrubber Waste Composition

Component	Concentration*
pH	8.3
Conductivity	30,000
Calcium	500
Chloride	1,000
Silicon Dioxide	30
Magnesium	10,000
Sodium	4,798
Sulfate	49,494
Total Dissolved Solids	69,805

*All concentrations in mg/l except pH (pH units) and conductivity (μmhos/cm).

At that point, it was agreed the construction would begin and a specimen of the backfill would be placed in a waste water bath as a check for compatibility. After one year of being immersed, another permeability test would be run to determine if there was any change in the permeability of the concrete. At the time of this paper, a year has not elapsed; therefore, these data are not available.

Since the backfill chosen was concrete, a "panel" method of excavation was required. In this method, a series of alternating panels referred to as primary panels are initially excavated. Following completion of at least two adjacent primary panels, excavation of an intermediate panel known as a secondary panel can begin. Due to the variability in the subsurface conditions, a system of pre-augering relief holes through the rock was conducted to facilitate the clamshell excavation.

STRUCTURAL DIAPHRAGM WALL

The majority of slurry cutoff walls for seepage control use either the S-B, C-B or plastic concrete method.

However, under certain circumstances a reinforced concrete slurry wall may be the most suitable method for waste containment. This was the case on a recent classified site.
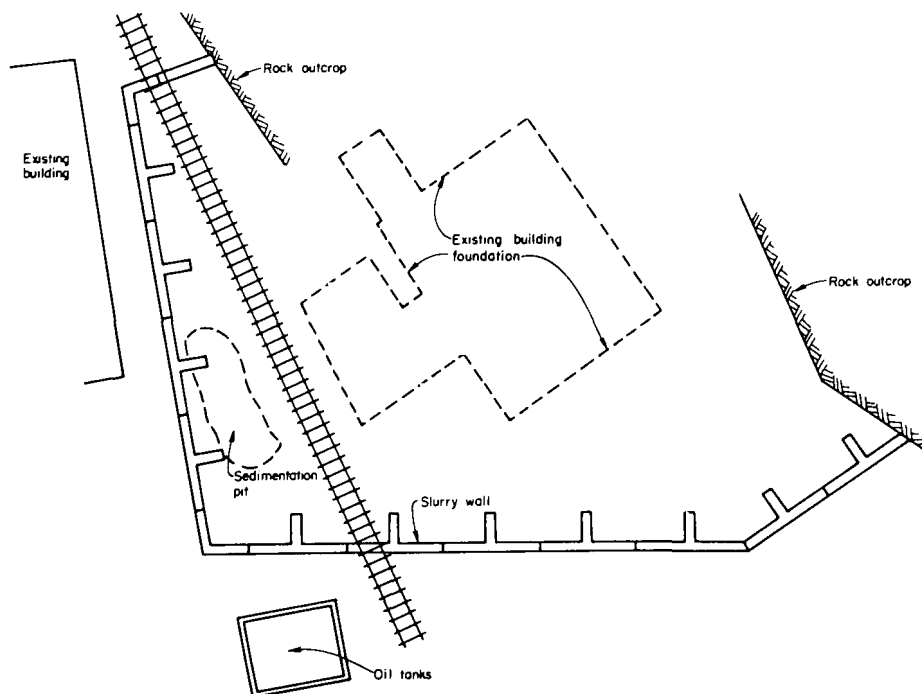
Figure 6
Alignment of Structural Diaphragm Wall at Classified Site
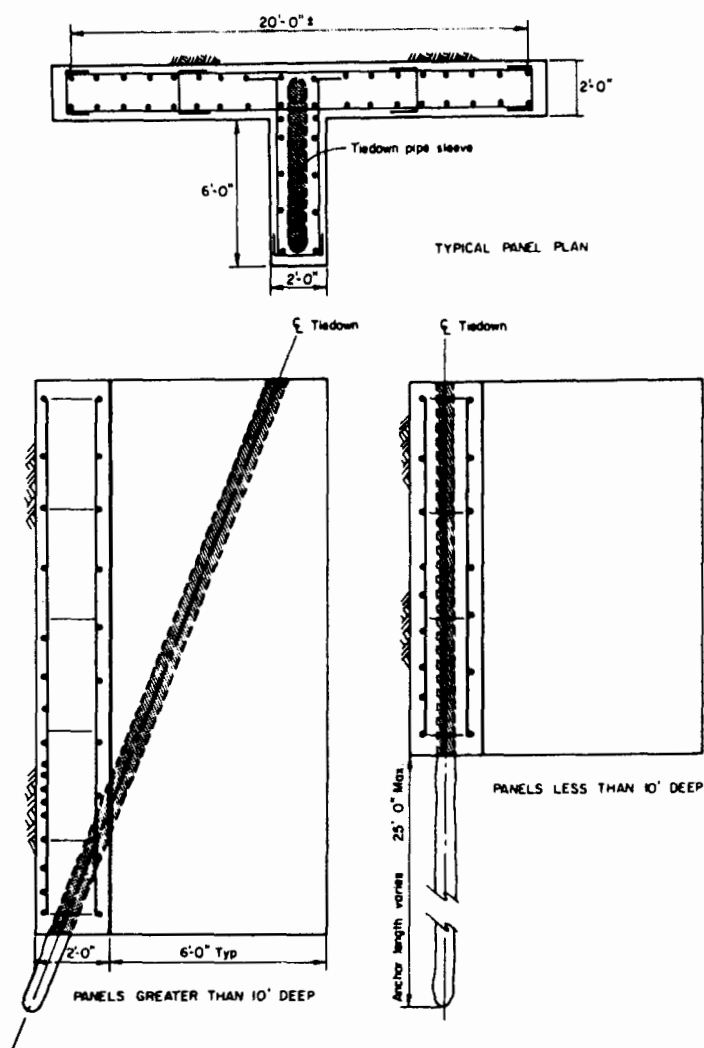
Figure 7
Typical Plan and Section of Structural Concrete Panel

The site, confined by structures making containment both difficult and expensive, is shown in Figure 6. Since the project was highly confidential at the bidding stages, neither the intended use nor final plan of the site was known by the invited contractors. All bids submitted for the project were rejected because they were over the owner's budget.

Contractor Input

After bids had been received and rejected by the owner, a meeting with the owner was requested to discuss the total plan in order to lower the cost of the initial proposal. The feeling was that if more parameters were known a change in design could be made to lower the cost of the project. During the meeting, it was revealed that the owner intended the cutoff as a temporary measure; the final goal was to remove the waste to a secure landfill. The original design was to install a C-B slurry wall barrier as the first of three separate contracts. The second phase was to excavate sheet piled pits in front of the wall replacing the contaminated soil with soil-cement in 10 ft wide alternating sections in front of the barrier to the top of the rock. This phase was not only very expensive, but also required a lot of manpower to work in a hazardous environ-

ment and handle hazardous material. The third contract would be to mass excavate the remaining soil and haul it to a secure landfill, replacing the soil with clean sand.

Once the final plan was known, the C-B barrier was redesigned as a structural diaphragm wall capable of withstanding the earth pressure and surcharge from the adjacent building. The wall could now serve as an impervious barrier and retaining structure.

Design

The slurry wall was designed in the shape of a "T" (Fig. 7) to develop more friction against movement at the bottom and reduce the size of the tiedown. The bracing system of the wall was designed using a tiedown that could be installed prior to excavation, thus minimizing exposure to the work force.

The original geological information indicated a sound, competent rock formation; therefore, a minimal key was designed. However, during the installation of the tiedowns, it was discovered that the rock had sand lenses throughout. This presented the possibility of waste channeling beneath the wall while the wall was serving as a barrier and allowing groundwater into the excavation during the removal of the waste. The implication for both cases would be economically disastrous, especially considering that the water entering into the excavation would have to be hauled to a secure landfill for treatment. The discovery of these lenses led to the design and installation of a cement grout curtain in the rock.

During removal of the waste, no seepage was reported entering the excavated pit. The structural diaphragm wall, although more expensive than the C-B wall, was less expensive overall since the second phase of the original design was eliminated.

CONCLUSIONS

The use of slurry walls has become an effective method for containing pollutants at waste sites. The types of slurry walls include soil-bentonite and cement-bentonite slurry trenches, plastic concrete and structural diaphragm walls. Some sites have special constraints or requirements which may influence the type of slurry wall used.

For complex or unique projects, the slurry wall contractor may be best qualified to determine the type of slurry wall and construction method. In these situations, a performance rather than prescription type of specification is preferred. This allows an experienced contractor to provide the most appropriate and economical solution to the problem.

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BARRIER-LEACHATE COMPATIBILITY: PERMEABILITY OF CEMENT/ASPHALT EMULSIONS AND CONTAMINANT RESISTANT BENTONITE/SOIL MIXTURES TO ORGANIC SOLVENTS

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INTRODUCTION

Organic solvents have been shown to increase the permeability of flow barriers constructed with compacted clay.[1-11] In addition, acids, bases, salts and organic liquids have been reported to increase the permeability of soil/sodium bentonite mixtures.[12,13] Nevertheless, barrier materials are widely prescribed to contain concentrated leachates, and millions of dollars are being spent to construct sodium bentonite cut-off walls around Superfund sites.

Some consultants and barrier material suppliers have suggested that "real world" leachates contain only low "parts per million" of organic chemicals. To support these claims, it has been stated that the concentration of most organic chemicals in leachate is limited by their low solubility in water. In fact, many of the most common and most toxic organic solvents are very sparingly soluble in water, but this does not mean that those solvents only exist at very low concentrations. Rather, it means that disposed organic solvents will often be present as a separate, immiscible and concentrated organic liquid layer.

Although large pools of organic liquids are rare at newly constructed disposal facilities, they are common at Superfund sites. Some have suggested there will almost always be enough water present in disposal sites to solubilize even the most sparingly soluble organic liquids. However, to better understand the large volume of water required to solubilize immiscible organic liquids, one should consider the volume of seawater required to solubilize oil slicks. For those organics having a solubility limit of parts per million, it would obviously require millions of gallons of water to solubilize only a few gallons. Although miscible organic liquids are usually diluted by water within a disposal site, even these miscible liquids may be found in localized high concentrations if little mixing has taken place.

The USEPA banned disposal of "free" liquids in landfills in 1982.[14] Immiscible organic liquids may, however, be present in sites where no "free" organic liquids have been disposed. Leaching studies were conducted using a mixture of sand and sorbents combined with 5% xylene, by weight.[15] This percentage of xylene is far below the concentration at which "free" xylene (as defined by the USEPA) would be present. After passage of two pore volumes of water through the mixture, as much as 46% of the xylene was released. This xylene was present as a floating immiscible liquid layer on the water that drained from the sand-sorbent mixture.

Considering the previous discussion, there seems to be a real need to set the following goals concerning remedial actions at abandoned sites:

• Increase the use of waste destruction, detoxification and treatment technologies in remedial actions at Superfund sites. This should coincide with a reduction in the use of containment technologies at these sites.

• For Superfund sites where it is not technically feasible to destroy or detoxify the waste, consider the following:

- compatibility tests between the most concentrated leachate at the site and the barrier material proposed to contain the leachate

- examination of alternatives to sodium bentonite as the containment material where acids, bases, salts or concentrated organic liquids are present in the leachate

Some alternative materials that have been suggested for containment walls include the following:

• Extruded clay minerals
• Non-bentonite clay minerals (e.g., kaolinite, attapulgite, etc.)
• Calcium bentonite
• Silica based gels and formulations
• Vertical membranes (HDPE, PVC, etc.)
• Contaminant resistant bentonite
• Cement/asphalt emulsions

In this paper, the authors report the findings of compatibility tests conducted on two of the above materials: a contaminant-resistant bentonite/soil mixture and a cement/asphalt emulsion.

PREVIOUS STUDIES

Contaminant resistant bentonites have been produced by several bentonite mining companies, drilling mud producers and even chemical companies in the United States and England.[12,13,16,17] While some have suggested that there is a contaminant resistant bentonite for every containment problem, few independent studies have been conducted to verify these claims.

In a study evaluating the permeability and chemical resistance of cement/asphalt emulsion fly ash mixtures, permeabilities decreased with time when the mixtures were permeated by water, an acidic solution and a neutral salt solution.[18] The mixtures consisted of 36% cementitious solids (fly ash and portland cement in several proportions), 52% asphalt emulsion and 12% water, by weight. The permeabilities of the mixtures initially averaged 6×10^{-8} cm sec^{-1}.

MATERIALS AND METHODS

Compatibility test results are normally reported as the permeability of a material during passage of two or more pore volumes of the permeant liquid. One pore volume is equal to the total volume of pores within a sample. If, for instance, a 1000 cm³ sample had a porosity of 0.4, then one pore volume would equal 400 cm³. Porosity of a sample can usually be calculated as follows:

$$1 - \frac{BD}{PD} = \text{Porosity} \qquad (1)$$

where:

BD = density of the bulk sample on an oven dry weight basis (gm/cm³)

PD = density of solids in the bulk sample on an oven dry weight basis (gm/cm³)

With a bulk density of 1.59 gm/cm³ and a particle density of 2.65 gm/cm³, the porosity of the sample would be 0.4.

Determining the pore volume of clay is relatively straightforward; however, this is not the case with materials such as asphalt emulsions. A significant portion of the asphaltic material would vaporize in any attempt to obtain an oven dry weight. Consequently, data are presented in this report in terms of permeability plotted over cumulative time instead of on a pore volume basis. This allows comparison between results obtained with the cement/asphalt emulsion and the contaminant resistant bentonite/soil mixtures.

Double-Ring Permeameters Used in the Studies

Permeability tests have been conducted on barrier materials using either fixed-wall or flexible-wall permeameters.[3] In fixed-wall permeameters, sidewall leakage can be substantial.[19] In flexible-wall permeameters, confining pressure may reduce the permeability of soft or remoldable barrier materials.[3]

Double-ring permeameters reduce the problems of sidewall flow and confining pressure. Confining pressures are not used with these devices, and flow near the sidewall is separated from flow through the central portion of the sample. Double-ring permeameters were originally suggested by McNeal and Reeve as a method of eliminating boundary flow errors.[20] More recently, it has been suggested that divided outflow permeameters (such as double-ring devices) may give more reliable permeability results than the traditional fixed-wall permeameter.[21]

Double-ring permeameters were used in all permeability tests discussed in this report. The permeameters were 15 cm in diameter and had double-ring base plates (Figs. 1 and 2). These base plates were fitted with drainage layers consisting of either a sheet of geotextile (cement/asphalt emulsion) or both geotextile and sand layers (contaminant resistant bentonite/soil). All permeability tests were conducted at hydraulic gradients of 36 except for approximately the last 100 days of the cement/asphalt emulsion tests. These tests were completed at an hydraulic gradient of 72. All permeability values given in this paper were obtained from the inner chamber of the double-ring permeameters. In this report, the terms standard leachate and water are used interchangeably.

Contaminant Resistant Bentonite/Soil Mixtures

A slurry composed of contaminant resistant bentonite and distilled water was prepared as suggested by the supplier using 90 kg bentonite/m³ of water.[22] Distilled water was mixed in a blender (on low speed), and the clay was slowly added until a 9% solution of clay was obtained. The slurry was poured first through a screen to ensure removal of any large aggregates of clay and then into the
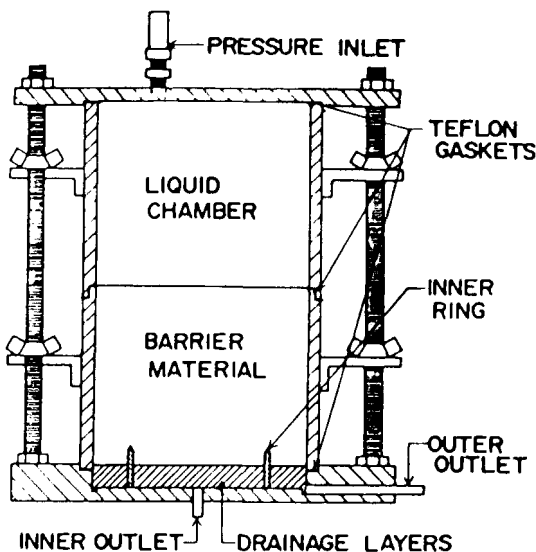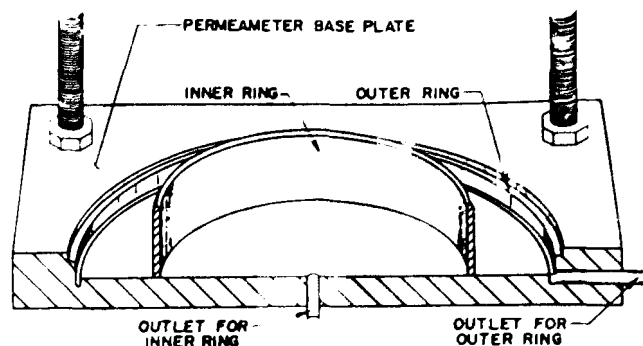
Figure 2
Details of the Base Plate to the Double-Ring Permeameter

15-cm double-ring permeameters. The filter cake that forms on the sidewall of a slurry trench was simulated by allowing the clay to settle out and form a 1-cm thick layer over an underlying sand layer.[23]

Calcareous smectitic clay soil was added to the nine percent bentonite slurry until a homogeneous paste was obtained. The soil-slurry paste had an average slump of 12.5-15 cm (as measured with a standard concrete slump cone). Moisture content and slump of the soil-slurry mixtures averaged 65% (dry weight) and 14 cm, respectively. The soil-slurry mixture was then poured into permeameters displacing the nine percent bentonite slurry.[19]

Permeability tests began by permeating the samples with a standard leachate (distilled water containing 0.005-0.010 N CaSO₄). After one month of permeation by water, an additional 5-cm thick layer of soil-slurry mixture was added to each permeameter. All soil-slurry mixtures were then permeated with the standard leachate for one additional month to obtain stable baseline permeability values.[23] At that time, the standard leachate was replaced with either a non-polar organic solvent (xylene) or a polar organic solvent (methanol). The physical and chemical properties of the permeant liquids used are reported in Table 1.

Cement/Asphalt Emulsion

Ingredients of the cement/asphalt emulsion were thoroughly stirred in the following proportions as suggested by the supplier:[24]
1. 36% asphalt emulsion
2. 52% clean sand
3. 8% clean water
4. 4% type 1 portland cement

The mixture was poured into the permeameter molds immediately after mixing to assure that the sand and cement remained in suspension. In a previous study, the material was found to shrink slightly as it cured into a plastic solid.[19] To obtain a good seal between the material and permeameter sidewall, it was necessary to cure the material under an overburden pressure of 0.5 lb/in.² After the first 24 hr of curing, the overburden pressure was removed and all permeability tests were conducted without overburden pressure.

All cement/asphalt emulsion mixtures were initially permeated with standard leachate (distilled water containing 0.005-0.010 N CaSO₄) for at least one month or until stable baseline permeability values were obtained. At that time, the standard leachate was replaced with either a polar organic liquid (methanol) or one of two non-polar organic liquids (xylene or creosote oil). (Table 1.)

RESULTS

Permeabilities of both the contaminant resistant bentonite/soil mixture and the cement/asphalt emulsion were evaluated using water, xylene and methanol as the permeant liquids. In addition, the cement/asphalt emulsion was permeated with creosote oil. Relatively low permeabilities were obtained with both materials when they were permeated by water. Results were, however, strikingly different when the barrier materials were permeated by organic solvents.

Figure 1
Schematic of Double-Ring Permeameter for Testing Barrier Material

Table 1
Physical and Chemical Properties in the Liquids Studied[23]

Property	Water (Standard Leachate)	Xylene (Nonpolar Solvent)	Methanol (Polar Solvent)
Density @ 20°C (gm/cm^{-3})	0.98	0.87	0.79
Viscosity @ 20°C (centipoise)	1.00	0.81	0.54
Dielectric Constant @ 20°C	80.4	2.4	31.2
Dipole Moment (debyes)	1.83	0.40	1.66
Water Solubility @ 20°C ($g L^{-1}$)	---	0.20	miscible
Molecular Weight	18	106	32
Melting Point (°C)	0	-47	-98
Boiling Point (°C)	100	139	65

NOTE: Creosote oil, which was also studied, is a liquid distillation product (200-400 °C) of coal tar consisting mainly of non-polar aromatic hydrocarbons along with some acidic and basic compounds. It is immiscible, has a density and viscosity greater than water and a dielectric constant much less than water.

Contaminant Resistant Bentonite/Soil Mixtures

Permeability values for the contaminant resistant clay based slurry ranged from 3 to 8×10^{-8} cm/sec when permeated by water (Figs. 3 and 4). When this material was permeated by either an immiscible or miscible organic liquid, however, it underwent large permeability increases.

Samples permeated by methanol exhibited stable permeabilities during the first 20 days of exposure to the polar organic liquid (Fig. 3). By the end of the first month, however, permeability of the clay-based slurry had increased from about 5×10^{-8} cm/sec to greater than 1×10^{-5} cm/sec.

Clay-based slurry samples began to undergo permeability increases within the first few days of permeation by xylene (Fig. 4).
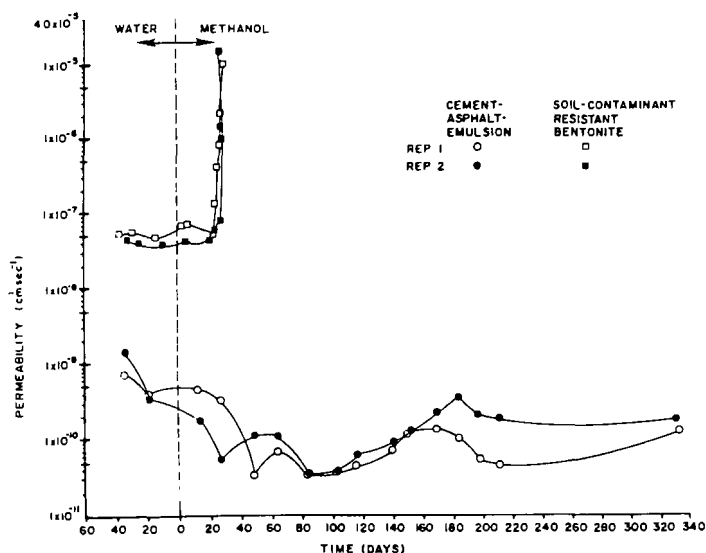
One of these samples underwent a more than two orders of magnitude increase in permeability within the first week of permeation by xylene. The other sample of clay-based slurry completely failed overnight. This failure and subsequent desiccation from direct exposure to pressurized air made it impossible to calculate the final permeability of the sample.

Cement/Asphalt Emulsions

Permeability values for the cement/asphalt emulsion (during the first month of permeation by water) ranged from 4×10^{-9} cm/sec to less than 1×10^{-10} cm/sec (Figs. 3-5). As seen in an earlier study, the permeability of this material decreased over the entire 30 days during which it was permeated by water.[18]

After stable baseline permeabilities were obtained, samples of the cement/asphalt emulsion were permeated by either polar (methanol) or non-polar (xylene and creosote oil) organic liquids (Figs. 3-5). Permeability values thereafter varied somewhat but, in all cases, the permeability remained below 5×10^{-9} cm/sec.

Samples permeated by methanol had permeabilities that varied over time from slightly less than 5×10^{-10} cm/sec to slightly greater than 3×10^{-11} cm/sec (Fig. 3). After 330 days of exposure to methanol, permeability of the samples appeared to stabilize in the range of 1 to 2×10^{-10} cm/sec.

Samples permeated by xylene had permeabilities that varied over time from 2×10^{-9} cm/sec to 4×10^{-11} cm/sec (Fig. 4). After 280 days of exposure to xylene, the range in sample permeability decreased to between 1 and 6×10^{-10} cm/sec.

Permeabilities varied from 1 to 3×10^{-9} cm/sec during the first 100 days of exposure to creosote oil. The range of permeability exhibited by these samples increased to between 5×10^{-9} cm/sec and 5×10^{-10} cm/sec during the second 100 days of exposure to creosote oil (Fig. 5).

CONCLUSIONS

The two alternative cut-off wall materials evaluated in this study were a contaminant resistant bentonite/soil slurry and a cement/asphalt emulsion. Permeability values of these materials to water were 5×10^{-8} cm/sec for the slurry and less than 5×10^{-9} cm/sec for the asphalt emulsion. In other words, the cement/asphalt emulsion was at most one tenth as permeable to water as was the contaminant resistant bentonite/soil based slurry.

When permeated by organic liquids, differences in the permeabilities of the materials greatly increased. Contaminant resistant bentonite/soil mixtures underwent permeability increases of from two to three orders of magnitude in three out of four cases. Permeability increases in the clay based slurry occurred within

Figure 3
Permeability of Cement-Asphalt Emulsion and Soil-Contaminant Resistant Bentonite to Water and Methanol
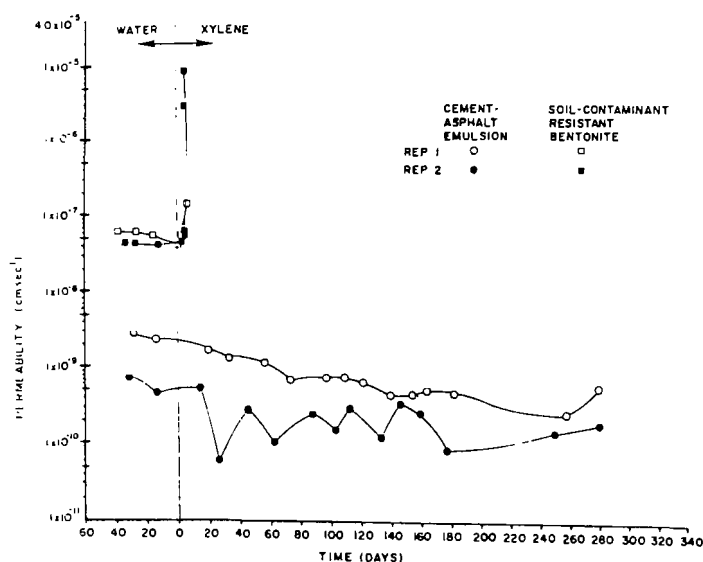
Figure 4
Permeability of Cement-Asphalt Emulsion and Soil-Contaminant Resistant Bentonite to Water and Xylene
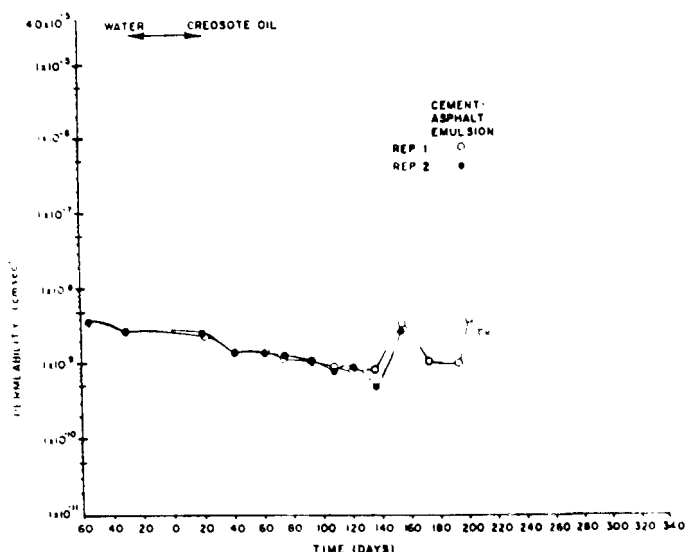
Figure 5
Permeability of Cement-Asphalt Emulsion to Water and Creosote Oil

either one week (for the xylene treated samples) or one month (for the methanol treated samples). When cement/asphalt emulsions were tested using permeameters, liquids and hydraulic gradients similar to those used with the clay based slurries, the following results were obtained:

•After permeation by methanol for 11 months, the permeability of cement/asphalt emulsion samples had decreased slightly from permeability values obtained with water.

•After permeation by xylene for over 9 months, the permeability of cement/asphalt emulsion samples had also decreased slightly from values obtained with water.

•After permeation by creosite oil for 5 and 7 months, permeability values of cement/asphalt emulsion samples were more variable than, but approximately the same as, for water.

Several studies have found that the permeabilities of clay liners and sodium bentonite slurry walls may be increased as the result of exposure to concentrated leachates. Since Superfund sites often contain such leachates, the following approaches should be adopted for remedial action at these sites:

•Reduce the role of contaminant technologies in remedial actions at Superfund sites

•Increase the role of waste destruction, detoxification and treatment technologies in remedial actions at Superfund sites

•For Superfund sites where the approaches suggested in 1 and 2 above are not technically feasible, alternatives to sodium bentonite slurry walls should be examined

In summary, the following points are important:

•Cement/asphalt emulsion exhibited a permeability to water an order of magnitude lower than that exhibited by the contaminant resistant bentonite clay based slurry.

•The clay based slurry exhibited large permeability increases when permeated by organic solvents. These increases occurred within one week for the non-polar solvent (xylene) and within four weeks for the polar solvent (methanol).

•When tested using identical permeameters, similar hydraulic gradients and the same organic solvents as were used on the clay slurry, cement/asphalt emulsions exhibited either steady or slightly decreased permeabilities after greater than nine months of testing. In addition, cement/asphalt permeated by creosote oil for seven months exhibited permeabilities of less than 5×10^{-9} cm/sec.

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A LABORATORY TECHNIQUE FOR ASSESSING THE IN SITU CONSTRUCTABILITY OF A BOTTOM BARRIER FOR WASTE ISOLATION

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INTRODUCTION

Block displacement, an innovative isolation technique developed during the last few years, has generated the need for scaled testing of the process. Under an SBIR grant from the National Science Foundation, a facility to conduct this model testing has been developed at Foster-Miller, Incorporated (FMI) in Waltham, Massachusetts. The facility permits one-tenth scale modeling of specific chemical waste site geologies to evaluate Block Displacement application under those specific site conditions.

Process Description

Block displacement is a method for vertically lifting a large mass of earth. The technique produces a fixed underground physical barrier placed around and beneath the earth mass. The barrier is formed by pumping slurry, usually a soil, bentonite and water mixture, into a series of notched injection holes. The resulting barrier completely isolates the earth mass from groundwater migration (Fig. 1). The barrier material should be compatible with in situ soil, groundwater and leachate conditions.

A bottom barrier is formed when lenticular separations extending from horizontal notches at the base of injection holes coalesce into a larger separation beneath the ground being isolated (Fig. 2). Continued pumping of slurry under pressure produces a large uplift force against the bottom of the block and results in vertical displacement proportional to the volume of slurry pumped.
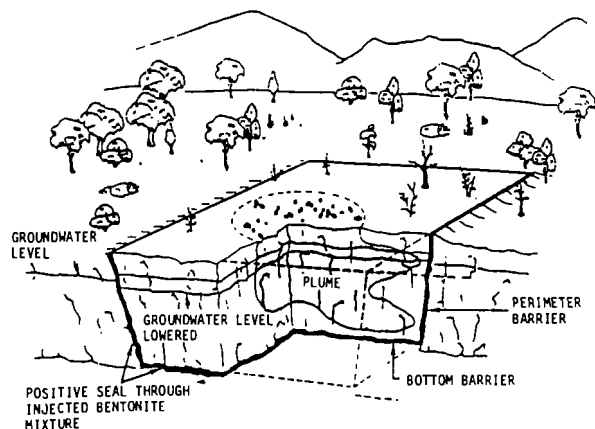
Figure 2
Creating Separation to Induce Displacement

A perimeter barrier is constructed in conjunction with the bottom barrier either prior to, during or following bottom barrier construction. The perimeter barrier can be constructed by various means including slurry wall, vibrating beam or jet grouting techniques. If constructed prior to bottom separation, the perimeter wall can be used to ensure a favorable horizontal stress field for proper orientation of the propagating bottom separation. A perimeter separation would first be constructed and then surcharged to increase the horizontal stress field in the formation (Fig. 2). Surcharge is additional pressure transmitted to the fluid slurry in the perimeter separation either by raising the slurry field level above ground level or by placing a seal in the perimeter separation and pressurizing the slurry below the seal.

The Block Displacement Method can be used to increase the width of an initially thin perimeter barrier such as might be constructed by vibrating beam or jet grouting techniques. To increase perimeter width by means of block lift, the perimeter must be constructed on a slight angle off vertical prior to the lift. The slight angle, Φ, off vertical tapers inward toward the block center. Upward displacement, d, of the block resulting from injection along the bottom barrier will then increase the perimeter separation, W_o, to the desired barrier thickness, W, according to:

$$W = d \sin \Phi + W_o \tag{1}$$

Field Experience

A field demonstration of this process has been completed, under USEPA sponsorship, adjacent to a National Priority chemical waste site near Jacksonville, Florida. The demonstration "block"

Figure 1
Block Displacement Barrier in Place
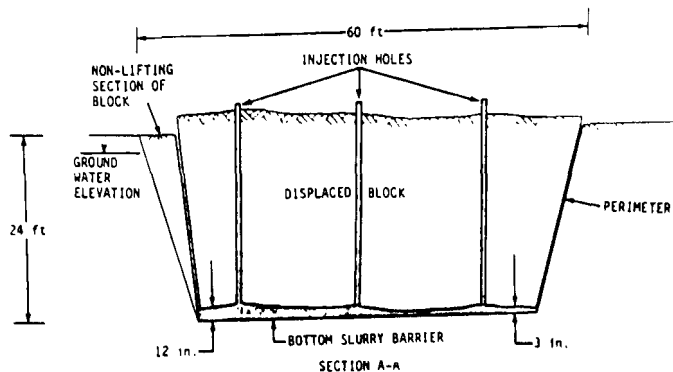
Figure 3
Final Block Displacement

was 60 ft in diameter by 23 ft deep and was composed of unconsolidated marine sediments.[1]

The test program successfully demonstrated the fundamental aspects of bottom barrier construction. A perpendicular cross section of the displacement of the earth mass is shown in Figure 3. Core samples were taken to verify the continuity of the bottom barrier in situ. Barrier thicknesses ranging from 5 in. to 12 in. were obtained.

The testing described in this paper was intended, in part, to model the USEPA field demonstration and help understand more fully the behavior observed during that demonstration.

Theoretical Basis

The theoretical basis for predicting the performance of the Block Displacement Process is founded in previous work applied to hydraulic fracture of rock formations. This earlier work was used to predict pumping pressures and flows as well as fracture orientation for oil recovery enhancement. The interaction of multiple, horizontally oriented fractures has been discussed by several investigators.[2]

A rigorous mathematical model has been developed[3] for predicting both fluid slurry properties and fracture propagation geometry for single and multiple interactive fractures. This model employs a surface integral approach utilizing dislocation theory to predict fracture behavior. Parametric inputs include slurry properties such as viscosity and pumping rate, and geologic properties including modulus of elasticity, poisson ratio, permeability and in situ stresses.

The work described in this paper compared the theoretically predicted behavior to that observed in the one-tenth scale model tests. Performance observed during these model tests was, in turn, compared to that observed during the full-scale field demonstration.

EXPERIMENTAL FACILITIES AND EQUIPMENT

Test Pit

The testing program was performed in the materials testing laboratory at FMI. A pit 7 ft wide, 12 ft long and 6 ft deep in the shop floor allowed for approximately one-tenth scale evaluation of the previous Florida demonstration. All testing was conducted in a uniformly graded concrete sand.

Instrumentation

Testing was monitored with a wide range of standard and custom built instrumentation.

Bentonite slurry properties were measured with a Marsh funnel, Shearometer, Fann filter press and unit weight bucket using standard API procedures. Slurry pressures during pumping were measured with standard pressure gauges.

In situ soil stresses were monitored using transducers developed specifically for this project. These were uniaxial, oil filled diaphragm type units designed to operate at pressure levels from 0

to 5 psi. These devices were used throughout the program to measure both horizontal and vertical stresses.

The need to determine the vertical displacement of the soil at several depths demanded the development of a simple yet accurate vertical displacement indicator. It consisted of a 2 in. diameter steel washer with a 36 in. long, 1/16 in. diameter wire welded perpendicular to the washer face. The washer was placed at the desired depth during soil backfilling. The washer was held in a fixed position relative to the soil around it while the wire slid through the overburden. The central hole in the washer allowed for the vertical stacking of displacement gauges at a single reference point in the horizontal plane. Using gauges at several levels, the vertical plane at which a fracture occurred was easily determined during testing.

Testing Procedures

During the full-scale demonstration of block displacement in Florida, a soil/bentonite slurry was pumped into drilled and cased holes that extended down 23 ft. These holes terminated in pancake shaped notches approximately 6 ft in diameter, produced by a horizontal hydraulic jet, rotated from the surface to erode a notch at the base of the drilled hole.

The cased boreholes and notches were simulated in the laboratory by tubes from the surface and specially configured notches placed during the preparation and compaction of the test bed. Thin metal discs covering 7 in. diameter gravel packs simulated the notch. This notch provided the reservoir of high pressure slurry from which the fracture developed.

For each test conducted, a specific test bed configuration was prepared, bentonite slurry was pumped into the tubes and notches, and pressures, flows and soil displacements were monitored and recorded. Depending on the plan, pumping continued until either a specific slurry volume had been placed, a target displacement had been reached or a fracture appeared at the surface.

Following the completion of each test, the pit was excavated and the resulting fracture network and seal configuration was observed.

TESTING

The testing program consisted of seven tests (Table 1).

The first four tests were preliminary in nature, serving to shakedown test equipment and procedures and to identify the adequacy and limitations of the instrumentation. During these tests, fracture mechanisms and slurry behavior were explored. Differences between the characteristics of the 4% and 8% bentonite slurries were documented. It was determined that the 4% slurry was superior for initial fracturing, while the 8% slurry tended to increase the final thickness of the fractures.

Table 1
Summary of Test Program

Test	Test Objectives	Test Specifications	Findings
1	Study initial fracture behavior, test laboratory procedures	Single well, 15 in. deep; 1.5 gal of 4% slurry	Horizontal fracture was formed, leak-off zone is clay filled
2	Study initial fracture behavior, refine procedures	Single well, 30 in. deep; 2 gal of 8% slurry	Permanent change in horizontal stress, conical and horizontal fractures found
3	Study fracturing to the ground surface. Compare the effects of 4% bentonite slurry and 8% slurry on fracturing	Single well, 20 in. deep; 8% slurry	3.5 gal of slurry pumped, fracture slope to surface mapped
4		Single well, 30 in. deep; 4% slurry	15 gal of slurry pumped, very large leak-off zone
5	Maximize fracture extent and thickness	Single well, 30 in. deep; 5 gal 4% and 7.5 gal 8% slurry	36 in. diam. bowl shaped fracture formed, 0.10 in. average thickness
6	Study fracture interaction	Three wells, 30 in deep, 24 in. apart; 8 gal 4% and 17.5 gal 8% slurry	Demonstrated coalescing of independent fracture
7	Demonstrate controlled displacement of block	Seven wells, 30 in. deep, 27 in. apart; 8 gal 4% and 36 gal 8% slurry	Lifted block 1 in. vertically and controlled that lift ±0.005 in. vertically

The designs of Test Nos. 5, 6 and 7 were based on the results of the earlier tests. The significant aspects of these tests are presented in the following paragraphs.

Single Point Well Test

The purpose of Test No. 5 was to maximize the extent, uniformity and thickness of a slurry-filled fracture produced from a single well point. A single notch was placed 30 in. below grade.

Based on the results of previous testing, fracturing was initiated with 5 gal of 4% bentonite slurry. After the initial fracturing, an 8% bentonite slurry was pumped to increase the vertical displacement. Black concrete dye was added periodically to the slurry during the pumping process to help identify the fracture zones during excavation.

The soil surface was displaced upward during this test, taking a domed profile with the largest displacement centered over the notch. This dome was over 5 ft in diameter and had a maximum vertical displacement of 0.3 in. at the center. Two feet from the center, the average displacement was 0.1 in.

Excavation of Test No. 5 revealed a bowl shaped surface approximately 3 ft in diameter. This surface was the top of the leak-off zone above the fracture. When this surface was excavated by cross sectioning, it could be seen that the top of the leak-off zone paralleled closely the actual fracture surface. One significant feature was the divergence of a single fracture into several, as the fracture surface extended radially from the notch. A second feature of the fractures that was revealed in the cross sectioning was the development of a dominant fracture. Many small fractures were present initially. However, as the thickened, lifting slurry was injected, a single fracture became dominant, causing all other fractures to arrest.

To test for the continuity of the seal, the "bowl" formed by Test No. 5 was filled with water to a depth of 4 in. The water level was monitored for three days. This test indicated that the seal was continuous. When the test block was cross-sectioned, the major fracture, in fact, was not found to be continuous over the entire surface. Rather, the clay permeated leak-off zones of unconnected fractures intersected, producing a continuous, low permeability barrier.

The most significant aspect of this test was the apparent continuity of the seal formed. Based on the results of this test, the leak-off zone could have a major effect on the overall permeability of the seal.

The 4% fracturing slurry followed by 8% displacement slurry appeared to work well as a system. This may be caused by the leak-off zone of the thin slurry generating an effect on the in situ stress field and soil permeability.

A major question in fracture mechanics is posed by this test. "As the fractures grow larger in thickness, do adjacent fractures coalesce or diverge?" Test No. 6, a three well point test, was designed to study the interactions of fractures.

Three Point Well Test

The purpose of Test No. 6 was to study the interaction of fractures propagating from three distinct injection points. Of primary interest was the behavior of the fracturing within the zone surrounded by the injection points. The test was intended to generate fracture seams between 0.25 in. and 1 in. in thickness. The three well points were set up in a triangular pattern, 24 in. from each other. Black cement dye was again added to the slurry to aid in discrimination during excavation.

The slurry injection process of Test No. 6 was conducted over a 2.25 hr period during which a total of 25.5 gal of slurry was pumped. The test ended when the slurry fracture broke to the sand surface.

The test began by pumping 7.5 gal of 4% bentonite fracturing slurry. This slurry was pumped sequentially to each of the three well points for 1 min each to assure that an equal volume of slurry was pumped to each well point.

Figure 4
Photograph of Excavated Test Block No. 6

Figure 5
Interaction of Two Fractures

After 7.5 gal of fracturing slurry were pumped, the mix was changed to the 8% bentonite lifting slurry. This mixture was pumped at 30 sec intervals, sequentially to each well point.

All of the displacement gauges indicated some lift during the test. The average displacement of the surface gauges was about 0.4 in. The maximum surface displacement was 0.48 in.

Several days after pumping, the overburden of sand was removed from the test pit, exposing the surface of the leak-off zone. Figure 4 is a photograph of this surface. The string grid evident in the fiture is on 2 ft centers at the level of the original ground surface.

The three injection wells, holes left by core sampling, a wire gauge and the fracture outcrop point can be seen in Figure 4. The block is approximately 6 ft by 5 ft and roughly circular.

A number of offsets can be seen in the fracture surface in Figure 4. The offset indicates that one fracture seam is passing under a second fracture, and that two fractures have not coalesced into a single seam. When the block was cross-sectioned, the interaction of two fractures could be seen much more closely.

An excellent example of fracture behavior is shown in Figure 5. As the fractures approach each other, they tend to diverge, one going up, the other down. After the fractures propagate past each other, they then tend to converge. Eventually the fractures connect and one leg continues growing while the other arrests.

The fracture seams were thinner and less well-developed at greater distances from the notch. Because of this, the interaction of fractures could be studied chronologically. By looking at two fractures at the block rim, and then excavating through them toward

the center of the block, the development of a fracture could be observed.

The fractures that were of greatest interest were those generated between the three well points. It can be seen in Figure 4 that the block surface is fairly level between the well points. The fractures appear to have a positive influence on each other in this area. When excavated, the fractures were fairly flat and fully interconnected forming a single fracture plane.

The most significant result of this test was the demonstration of the interaction between fractures. The test demonstrated that independent fractures do tend to coalesce and form a single fracture. The test also indicated that fractures started from independent sources will also coalesce, and that these fractures have a positive influence on each other. The fractures between the three well points tended to be flatter and thicker than those beyond the well point boundary.

Seven Well Point Block Displacement

The purpose of this test was to demonstrate the key features of the block displacement process. Test No. 7 was a 1/10 scale model of the geometry of the USEPA-Florida, Block Displacement test site. The plan was to create a set of fractures from seven injection wells, to consolidate these fractures into a single continuous clay layer and then displace the block 1 in. vertically in a controlled fashion.

In this test, an artificial perimeter was constructed to define the sides of the block, much as a slurry wall would in a full-scale lift.

The test was further intended to demonstrate that once an artificial geologic layer has been created it can be remobilized, and the block further displaced upward in a well-controlled fashion.

The last major purpose of the test was to demonstrate the continuity of the clay layer by conducting a leak test. From this test, an effective permeability could be calculated.

The laboratory setup is shown in Figure 6. This photograph was taken after the block had been displaced 1 in. vertically.

There were seven injection wells in this test. The wells were 27 in. apart, forming a hexagonal pattern about the central well. At the base of each well, 30 in. below grade, was a 7 in. diameter artificial notch.

An artificial perimeter was constructed for this test to define the block size and to control the extent of fracturing. This perimeter was made of a plastic sheet placed in the soil. The perimeter was 6 ft in diameter at the ground surface and tapered inward 1.5 in. at the perimeter to a 5.75 ft diameter base at a depth of 30 in.

The soil displacement was measured with 18 dial gauges mounted on a stationary steel frame. These gauges allowed continuous monitoring of vertical displacement during the test.

The initial test consisted of fracturing and lifting the block 1 in. vertically. This was done by pumping 35 gal of mud during a 2 hr period. After the initial test, the block was reactivated and lifted in small increments periodically over several weeks. Finally, after the vertical displacement testing was completed, a leak test was performed to assess the effective permeability of the installed seal.

The first step in block displacement is to hydraulically fracture a basal plane under the soil to be lifted. From the previous tests, it was determined that a thin slurry was the most effective fracturing fluid. In Test No. 7, 8.5 gal of 4% bentonite slurry were used as the fracturing fluid. As this slurry was injected, the pumping pressure slowly rose to 7 to 10 psi at the notch, and then quickly dropoped off to 2 psi as the soil fractured. This process, the pressure slowly rising and then quickly dropping off, repeated itself as the block fractured.

After a basal plane was fractured under the block, this fracture was expanded vertically to displace the block. An 8% bentonite slurry was used as a displacement mud. The pumping pressure initially rose to 15 psi. After pumping 19 gal of lifting slurry, the pumping pressure had dropped to 3 psi. This is approximately 1 psi above overburden pressure.

The slurry was pumped sequentially to each injection well. The vertical displacement of the block determined the amount of slurry pumped to each well. A dial gauge recorded the vertical displacement at each well point. During the test, each well point was lifted sequentially 0.025 in. Over the 6 ft diameter of the block, the surface could be held level within ± 0.005 in. during the entire block lift. Scaling this to a full-scale lift, each well was lifted in increments of 0.25 in., and the block was held level within 0.063 in.
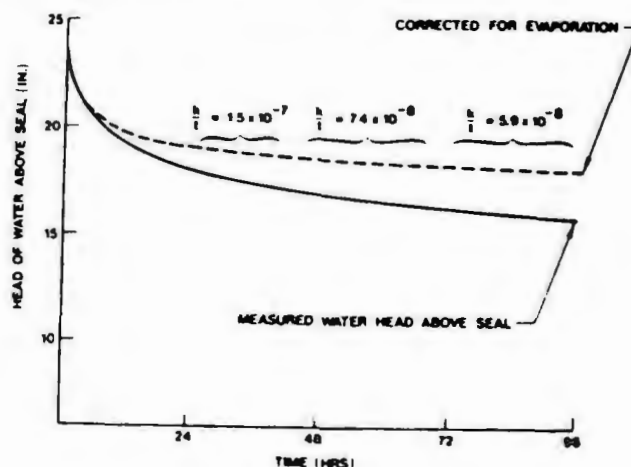
Figure 7
Leakage Resistance, Permeability/Seal Thickness

After the first day of testing, 35 gal of slurry had been pumped and the block had been lifted 1.04 in. Over the next 15 hr., with no pumping, the block settled 0.48 in. This settling was caused by water leaking from the bentonite slurry. In practice, this settling would be much less due to the structural bulking of the soil component of a soil bentonite slurry. In these 1/10 scale tests, no soil is added to the slurry during lift.

On the second day of testing, the block was relifted. When slurry pumping resumed, the pump pressure peaked at 9.5 psi and then broke back to 3 psi. This was a typical pattern throughout the subsequent lifts. It required 7.5 to 10.5 psi to reactivate the fracture and 2.5 to 3.5 psi to lift the block. This is 0.5 to 1.5 psi greater than the overburden pressure.

The block was lifted a total of 2.52 in., settled 1.59 in. and had a net vertical displacement of 0.93 in. The maximum displacement was 1.04 in., on the first day of testing. The maximum settlement was 0.48 in., between the first and second test days.

A total of 44 gal of slurry were pumped during the test; 8 gal of 4% bentonite fracturing slurry, and 36 gal of 8% bentonite lifting slurry.

Figure 6
Laboratory Demonstration of Block Displacement Test No. 7

At the conclusion of the block displacement test, a leak test was conducted to determine the average permeability of the bentonite seal.

This leak test was the analog of a field draw down test. In a field situation, a draw down test is the only practical test of seal continuity. The seal cannot be excavated and examined as it can in the laboratory environment. The block, as defined by the plastic perimeter and basal displacement fracture, was filled with water. The water level was observed over the next 96 hr (Fig. 7). Above the graph is the average leakage resistance as defined by k/t, permeability/seal thickness.

During excavation, the entire overburden of sand and the plastic sheet perimeter were removed. The exposed leak-off zone surface, the block perimeter and two exploration trenches are shown in Figure 8. The shape of this fracture surface is roughly the intersection of seven bowls, each bowl centered about a well point.

The six outer bowls have been truncated by the perimeter. In general, the leak-off zone surface parallels the clay fracture seam. The leak-off zone does tend to be thicker above the notches.

A cross-section through the block is shown in Figure 9. The scale below the central well is marked in 1 in. increments. The major feature of this cross-section is the continuous fracture seam, approximately 1 in. thick, traversing the entire block. The leak-off zone, especially around the central well, is also clearly visible in the photograph.

Two other features can also be seen. A number of small fractures are visible above and below the main fracture. It is believed that
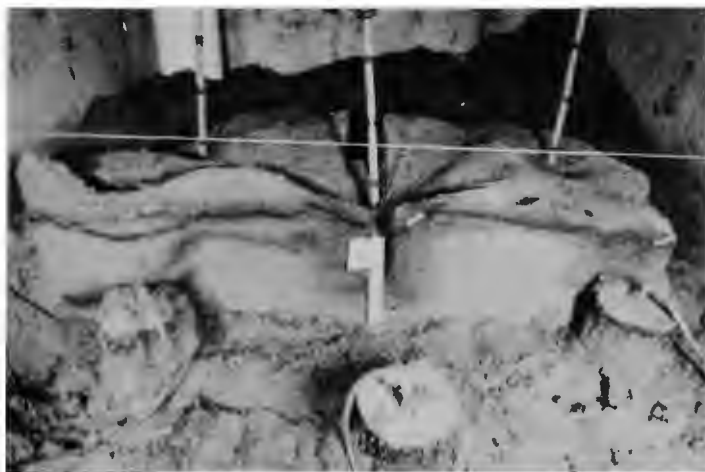
Figure 10
Photograph of Cross Section Fifteen Inches South of Central Well Point,
Test No. 7

these fractures developed concurrently with the main fracture. As the main fracture developed, the development of these secondary fractures was arrested. The central bowl shape can also be seen clearly in this cross-section.

The typical "inverted top hat" configuration of the fractures around the notches is shown in Figure 10. At the notch edge, the fracture tends to rise vertically for a few inches and then abruptly turn horizontal. This is due to a local shear feature in the soil, caused by the structural rigidity of the steel notch cap. This result seems to be a flaw in the modeling procedure; however, this localized shear failure appears to be confined to the notch area with little overall effect. It can be seen in the photograph that a single horizontal fracture traverses the block between the notches.

The most significant feature of this test was the well controlled lifting of the test block. This test demonstrated that a single horizontal fracture surface could be produced under a block of soil and then widened by lifting the block vertically in a controlled manner. The test also demonstrated that fractures emanating from independent wells will influence each other in a positive way, and, given sufficient vertical displacement and horizontal extent, fractures will coalesce into a single plane.

Test No. 7 was the first test in which a leakage test could be performed. The positive result is significant for future field applications as a draw down test would be the proof of a complete barrier. For this laboratory test, the leakage rate out of the block was measured rather than the groundwater infiltration rate, as might be done in the field.

Test No. 7 provided an initial exploration of fracture mechanics in unconsolidated soils. This behavior must be further evaluated for varying conditions. One of the most critical variables is the groundwater table. Test No. 7 was run above the groundwater table. Other parameters such as soil grain size, soil layering and soil stress must be evaluated.

CONCLUSIONS

The tests conducted to date have indicated that fracture interactive processes and displacement control processes can be studied for specific geologic conditions. The fracture initiation behavior from each disc shaped notch, however, does not appear to be adequately modeled. The influence of the simulated notch and/or the use of nonscaled soil grain size may be contributing to this inadequacy.

The apparent deviation from predicted full-scale behavior is a local steeply rising shear fracture which then turns horizontal and extends from there as predicted. This discrepancy has not had significant impact on the overall test results as it extends over a distance of only 2 to 3 in. from the tip of the simulated notches.

Figure 8
Excavation of Test No. 7

Figure 9
Photograph of Cross Section Six Inches North of Central Well Point,
Test No. 7

The prediction that the fractures remain horizontal over a substantial distance and the prediction that the influence of the free surface will dominate over in situ stress and viscosity effects has been demonstrated. The favorable influence of slurry leak off on local stresses has been shown to be significant in keeping the fractures horizontal by locally increasing the horizontal stress.

Comparisons between the performance of the 1/10 scale model tests and observations in the field demonstration are limited. To date, the model tests have not been performed under fully saturated soil conditions, whereas the field demonstration was performed in saturated sand with a groundwater table only a few feet below the surface. The scaled pumping pressure and lift geometry appear similar. The field demonstration was hindered by unsatisfactory perimeter conditions, prohibiting a complete comparison. However, local surficial soil deformation and displacement behavior were similar for the full and 1/10 scaled tests.

The 1/10 scale facility can be used for future testing to evaluate the influence of groundwater as well as for modeling other geologic conditions including stratification, discontinuties, large grain size material such as boulders or cobbles and irregularities in surface topography. The influence of perimeter construction technique and construction sequencing can also be evaluated.

The field testing of the block displacement process carried out under funding from the USEPA and the laboratory studies carried out under a grant from the National Science Foundation show that block displacement is a viable technique both theoretically and practically for introducing horizontal low permeability layers into unconsolidated soils.

It is believed that block displacement can be a powerful tool in the control of hazardous waste.

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EXPLOSIVES WASTE DISPOSAL SITES: A DOD-WIDE PROBLEM CASE STUDY:
Milan Army Ammunition Plant O-Line Settling Ponds

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INTRODUCTION

The disposal of explosives-laden waste water from munitions manufacturing prior to implementation of currently acceptable environmental controls (e.g., filtration, activated carbon absorption) commonly entailed the use of earthen surface impoundments (ponds) in conjunction with drainage ditches. This procedure resulted in contamination of surface and groundwater and associated soils and sediments. To prevent additional environmental damage, remedial actions must be undertaken. These actions must be based upon site investigations and proper planning/design of the appropriate remedial cleanup measures.

In this paper, the author describes the site investigation and remedial action (under construction) at the O-line settling ponds located at Milan Army Ammunition Plant (MAAP), Milan, Tennessee. This project has been implemented as part of the U.S. Army Installation Restoration Program through the U.S. Army Toxic and Hazardous Materials Agency located at Aberdeen Proving Ground (Edgewood Area), Maryland. The assistance of MAAP, the U.S. Army Engineer Division, Huntsville, and the U.S. Army Engineer District, Mobile, has been instrumental in the progress of this action and is greatly appreciated. ·

Figure 1
Location of City of Milan, Milan Army Ammunition Plant, and the O-line
Settling Ponds

SITE DESCRIPTION AND HISTORY

The 12-acre O-line settling ponds sites is located within MAAP, approximately 5 miles east of the City of Milan, Tennessee (Fig. 1). The ponds are part of the O-line facility that is used for conventional munition demilitarization. Defective and outdated munitions loaded, assembled and packed (LAP) at the plant were disposed at this line.

The major function of O-line was to remove explosives (2, 4, 6-trinitrotoluene (TNT) and cyclotrimethylenetrinitramine (RDX) from bombs and projectiles by injecting a high pressure stream of hot water and steam into the open cavity of the munitions. Waste explosives were separated from the resulting water phase and collected for reuse or for disposal at the MAAP explosive burning grounds. Effluent washwater was then passed through baffled concrete sumps outside the wash-out building where it was cooled and entrained explosives particles were removed by screens. Cooling was aided by a cold water spray at the surface of the sump chambers. The screens and sumps were periodically cleaned to remove collected explosive particles.

Until 1941, the water effluent from the sumps was discharged to an open drainage which ran through the O-line area. In 1941, holding ponds were constructed at the site to provide an additional settling capacity for the waste water. The ponds consist of 11 individual basins connected by spillways and open ditches with baffles and distribution boxes to allow several configurations of ponds to be employed in series (Fig. 2). The ponds have a total capacity of approximately 5,500,000 gal and cover an area of about 280,000 ft^2 (excluding the dikes).

In operation the ponds received water from the plant sump through an open concrete flume. Most of the solid explosive particles settled to the bottom of the first receiving basin. Effluent from the last basin in the series overflowed through a bank of carbon-filled tanks before being discharged to the area drainage ditch. The carbon from the tanks was periodically removed and burned. The drainage ditch ultimately discharged across the north boundary of the installation to the Rutherford Fork of the Obion River.

In 1971, sediments were dredged from the ponds using a drag line, and the dredged spoils were placed at the northwest corner of the pond area. An attempt was made to burn the sediments at the explosives burning ground; since the material would not burn, the remaining dredged spoils were left in the area.

In 1981, MAAP drained the ponds, treated the effluent, moved the spoils pile back into the dredged ponds and lined the empty

Figure 2
0-line Settling Ponds with Spillways and Baffles

Figure 3
Geologic Cross Section for Milan Army Ammunition Plant

Monitor well installations were based on the geohydrologic setting present at 0-line. Available information indicated the Claiborne and Wilcox formations as the shallow water bearing units (aquifer) underlying MAAP. These formations consist chiefly of sands with lenses and interbeds of clay at various stratigraphic horizons with an average total depth of 300 ft beneath MAAP (Fig. 3). Groundwater flow at the site was thought to be in a northwest (NW) direction, and this was close to the actual situation at the 0-line site. However, the direction of groundwater flow at MAAP is greatly influenced by topography and surface streams that alter flow patterns throughout the plant (Fig. 4). Depths of the wells varied to monitor the upper, middle and lower portions of the aquifer for explosives contamination. The correct placement of monitor wells was essential in evaluating the magnitude of contamination originating from the site. In this case, monitor wells were placed downgradient of groundwater flow from the settling ponds within distances where contamination was anticipated to be present based upon groundwater hydraulics of the area.

Water samples were collected from the drainage ditch, settling ponds and groundwater monitor wells. Analysis was done for explosive compounds and associated degradation products (Table 1). In addition, geohydrologic information was collected from the monitor wells (Fig. 5) to define groundwater flow, soil types and groundwater hydraulic properties specific to the site.

Results of the sampling indicated the 0-line settling ponds and associated groundwater as major areas of contamination. Sediments from the ponds indicated up to approximately 5% explosives content in the top 12 in. of materials (Fig. 6). These concentrations decreased with increasing depth of sediment indicating leaching of contaminants into the subsurface zones. Groundwater was contaminated with explosives 1.25 miles downgradient of the settling ponds (Figs. 7, 8 and 9) and flowing in the north-northwest (NNW) direction. The contaminated groundwater zone (plume) was limited to the middle section of the Claiborne Formation indicating vertical stratification of the contaminants. Some levels of contaminations were above U.S. Army Interim Drinking Water Criteria (RDX-34 μg/l and TNT-44 μg/l).

The presence of explosives at high levels (Fig. 10) adjacent to the settling ponds and the existence of a sizeable plume migrating toward the installation boundary adjacent to the Rutherford Fork of the Obion River indicated a need for remedial action to prevent further environmental damage. Samples collected in the drain-

ponds with synthetic liners as a temporary remedial measure to prevent additional groundwater contamination.

SITE INVESTIGATION

Field investigations were conducted at MAAP and the 0-line area in order to define the magnitude of contamination resulting from the 0-line operation. To evaluate the impact of the 0-line settling ponds site on the environment, production records were reviewed to assess the amounts and types of waste disposed at the site. In addition, geohydrologic information, topographical data and meteorological data pertinent to the area were reviewed to determine probable pathways of contaminant migration (e.g., 246-TNT and RDX) from the site.

Results of this review determined that explosives contamination migration was probable via two mechanisms: (1) surface water migration of explosives by means of the drainage ditch located in and adjacent to the 0-line area; and (2) groundwater migration of explosives by means of the settling ponds and, to a degree, the drainage ditch. Both the settling ponds and drainage ditch allowed for infiltration of explosives into the groundwater flow system beneath MAAP when waste water was present. The extent of contamination from the site could not be assessed from the review. Actual installation of monitor wells and collection of environmental samples from the area for chemical analyses was required.

Figure 4
Piezometric Surface of Groundwater in the Claiborne Formation

Table 1
Explosive Compounds and Associated Degradation Products

2, 4, 6-Trinitrotoluene (246-TNT)
1, 3, 5-Trinitrobenzene (135-TNB)
2, 4-Dinitrotoluene (24-DNT)
2, 6-Dinitrotoluene (26-DNT)
1, 3-Dinitrobenzene (13-DNB)
Cyclotrimethylenetrinitramine (RDX)
Cyclotetramethylene Tetranitramine (HMX)

age ditch indicated explosives were present, but the low levels found (under 50.0 mg/kg) did not justify additional study or remedial actions.

REMEDIAL ACTION

Various remedial action (closure) alternatives were considered for use at the 0-line settling ponds site. These include:
- In-place containment using migration barriers such as containment walls and low-permeability caps
- On-site treatment of sediments using rotary kiln incineration
- On-site waste disposal in a newly developed facility
- Removal and off-site disposal/treatment

The selection of a remedial action was largely restricted to the in-place containment option due to restrictions on disposal of reactive wastes (i.e., explosives) into landfills and the lack of proven technologies (e.g., incineration) for treatment. Treatment technologies are currently being developed and should be available within the near future for treatment of explosives waste. These technologies are needed for sites where an in-place containment action is not suitable as a means of closure.

The 0-line site was very favorable to an in-place containment closure. The geohydrologic conditions at the site provide for adequate isolation of the waste materials after installation of the low permeable cover system (grass/topsoil/clay-gravel-clay) and containment wall. The depth of groundwater below the ponds, sur-

Figure 6
0-line Settling Pond 3-Inlet; Contamination Profile
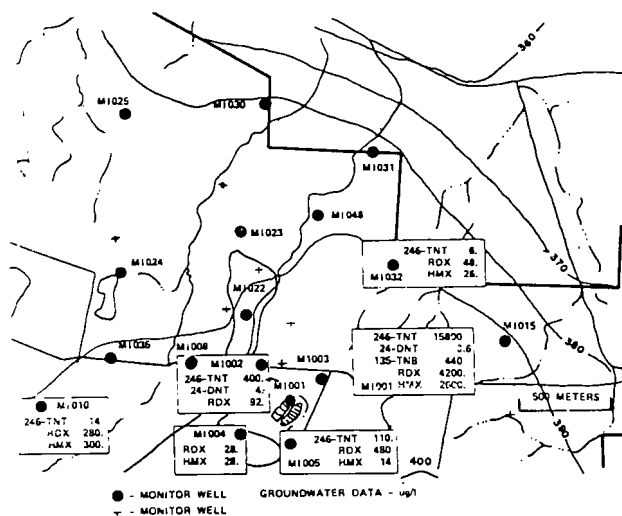
Figure 7
Groundwater Contamination in the Upper Section of the Claiborne Formation
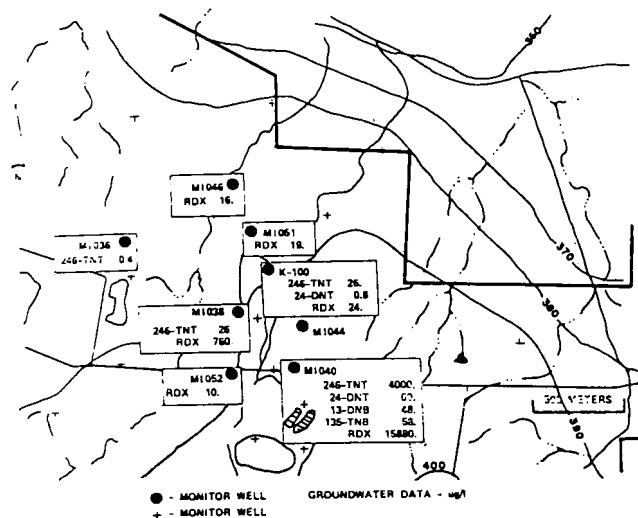
Figure 8
Groundwater Contamination in the Middle Section of the Claiborne Formation

Figure 5
Monitor Wells Located in the Vicinity of the 0-line Settling Ponds
(Reprint with permission from USGS Quadrangle, Atwood, Tennessee)

CONTAMINATED GROUNDWATER CONTROL 143
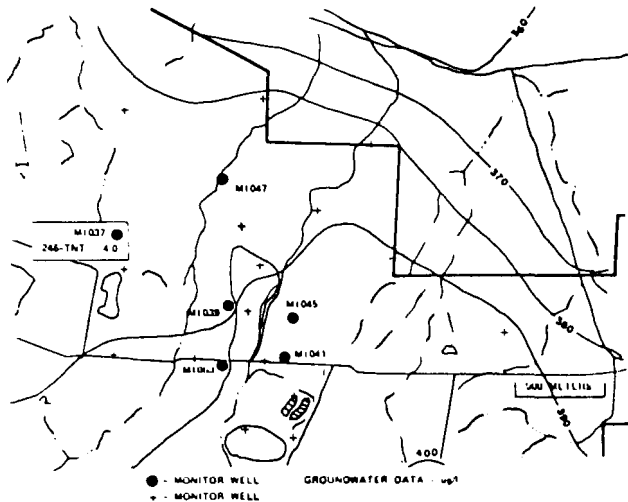
Figure 9
Groundwater Contamination in the Lower Section of the
Claiborne Formation
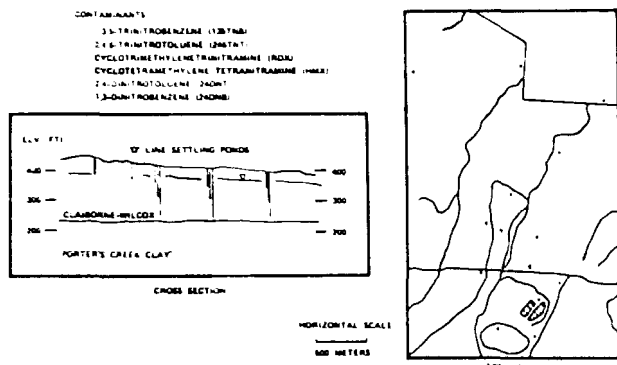
Figure 10
0-line Settling Ponds Groundwater Contamination Plume

leach and migrate into the groundwater flow system. Groundwater depth at the 0-line site is approximately 40 ft below the bottom of the ponds. This depth is more than adequate for the containment system.

Construction of the containment system required an assessment of the explosive potential of the sediments prior to any actual earthmoving operations. The low content of explosives in the sediments indicated a minimal potential for any ignition of explosives. However, testing was conducted to determine if ignition could occur due to localized stresses on the sediments due to heavy earthmoving equipment.

A friction test using the U.S. Bureau of Mines Pendulum Friction Apparatus was conducted on sediment taken from the site. The sediment was mixed with explosives at various levels ranging from 0-25%. Results indicated that sediments with up to 20% explosives were insensitive to the testing procedure with no moisture present in the sample. The presence of moisture and a maximum concentration of approximately 5% explosives in the 0-line site sediments indicated earthmoving operations could be performed.

Construction is currently in progress at the 0-line site in MAAP. Following completion in the fall of 1984, a monitoring program will be initiated to monitor groundwater for explosive compounds. The effectiveness of the closure will be evaluated based upon the results of this monitoring.

Figure 11
Profile of Recommended Cover Configuration

face drainage and soil types are adequate to prevent surface water and groundwater from contacting the contaminated sediments and forming leachate that could flow into the groundwater system beneath the ponds. In addition, borrow material (e.g., clay, inert fill used for construction) is available at MAAP

The closure at 0-line (Fig. 11) acts primarily as a diversion for surface water from contacting the contaminated material in the ponds. A cross-section of the cover system (Fig. 12) illustrates the method by which water is diverted. The system utilizes a proper grade that allows a large portion of precipitation to runoff the site or be removed through evapotranspiration of the grass cover. Any remaining portions of water percolate through the upper soil into a gravel drain layer that allows for additional runoff. The gravel layer contains a perimeter piping system that routes collected water to the outside of the cover system.

The clay layer is the final protective layer in the system. This layer is designed to prevent percolation of water for an extended period. By compaction of low permeability clays, percolation of water is prevented until residual water in the drain layer causes saturation. However, the rate of percolation through the layer after saturation is minimal, restricting the flow of leachate into the groundwater flow system. Any possibility of lateral movement of infiltrating precipitation into the ponds is prevented by the perimeter containment wall obstructing flow toward the ponds.

Adequate depth to groundwater below the ponds is required when using an in-place containment system. The bottom of the ponds should be a distance far enough from the groundwater surface and capillary fringe area so that contaminated sediments are not in contact with groundwater. Otherwise, contaminants will

LTC - Liquid Transmission Control
DI - Diversion Interface

α - Slope Angle

Figure 12
Liquid Routing Diagram of Cover Configuration

CASE HISTORY ORGANIC RECOVERY AND CONTAMINANT MIGRATION SIMULATION

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INTRODUCTION

A continuing concern associated with evaluation of hazardous waste sites and groundwater contamination is the investigation, identification and elimination of potential pathways of contaminant migration. In this paper, the author describes a successful project at a site which involved a myriad of horizontal and vertical pathways. Migration of significant concentrations of organic contamination, including free phase chemicals, occurred through pilings, shallow permeable lenses and old well annular spaces. The approaches and techniques which the author employed, such as computer modeling, can prove to be very useful in similar future efforts.

BACKGROUND

The site investigation and remedial evaluation discussed in this paper were completed at a chemical plant site located in an industrial district adjacent to the Mississippi River. The plant, which began operating prior to World War II, manufactures chemicals including chlorinated organics such as ethylene dichloride (EDC). Intermittment spills, reboiler cleaning operations and leaking pumps contributed EDC to a receiving stream located within the plant. These discharges were discontinued or more closely controlled after the early 1970s.

Being heavier than water, the free phase organics accumulated in ponding areas located within the stream channel and migrated vertically and horizontally through the underlying soil.

Routine shallow RCRA groundwater monitoring revealed the presence of dissolved EDC in some wells. Testing of plant water-supply wells indicated that EDC was also present in concentrations as high as 20 mg/l in limited portions of a major industrial aquifer located at depths of about 250 to 400 ft below the plant grade. Groundwater from this aquifer is used by the area plants for cooling water. Additional monitoring wells completed to depths varying from 30 to 150 ft adjacent to the wells of concern, confirmed the presence of subsurface free phase organics.

During the workover of a plant active well, screened in the 400-ft formation, free phase organics were detected leaking into the well through a hole in the well casing and were recovered.

The initial observed pattern of subsurface contamination suggested several possible migration pathways into the lower aquifer.

OBJECTIVES

The purpose of the investigation by D'Appolonia Waste Management Services was to assist plant personnel in determining the pathways producing aquifer contamination and in implementing remedial measures. The specific objectives of these efforts were to:

- Assist in managing and conducting a shallow groundwater contamination assessment and recovery program to define the mechanism by which organics were contaminating the underlying aquifer and to remove contaminant sources
- Simulate regional groundwater flow in the underlying aquifer to assess the potential for off-site migration and to maximize the containment and removal of the contaminant plume, regardless of changes in the pumpage of nearby wells at adjacent plants

COMBINED PROGRAM

The investigation and recovery program were integrated into a combined program in order to expedite control of the source of the contamination and reduce program costs. The general approach of the program is outlined below:

- Research historic plant operations, locations of former plant facilities and review plant geotechnical boring data
- Plug all abandoned water-supply wells
- Seal the annular spaces in all operating water supply wells
- Complete borings to define the horizontal and vertical extent of the shallow contamination. Where free phase organics were encountered, the borings were completed as recovery wells. Recovery wells were tested to facilitate design of the final recovery program and assess migration rates.
- Implement a continuing test program for the approximately 15 active water-supply wells and 30 recovery wells. Complete water-supply well testing to define aquifer characteristics.
- Compile and analyze regional aquifer information to define aquifer gradients and the boundary conditions for aquifer modeling
- Examine chemical species data from water-supply wells and recovery wells to identify potential sources, trends and effectiveness of remedial actions
- Simulate regional groundwater flow for various aquifer pumping scenarios
- Simulate contaminant mass transport and dispersion associated with alternative hypothetical sources and compare with the field-observed contaminant distribution
- Simulate alternative remedial pumping scenarios in order to evaluate long term aquifer cleanup
- Perform laboratory testing of artifically contaminated aquifer media samples to assess retardation factors (attenuation) and simulate long-term aquifer cleanup

SHALLOW CONTAMINATION ASSESSMENT

During an eight month period, the plant engineering staff, supported by D'Appolonia, managed and implemented a shallow

drilling and recovery program to determine the mechanism of contaminant entry into the underlying aquifer and to remove the suspected source(s). The objectives of this program included:

•Characterization of the geology of a complex depositional environment
•Mapping of the migration pathways
•Estimation of the sources and mass of shallow subsurface contamination
•Delineation of a cost effective method of contaminant removal

At the time of paper preparation, 33 shallow piezometers (previously installed), 30 recovery wells, four monitor wells and ten test borings have been completed at the site; the most recent are shown in the general plant plan view (Fig. 1).

The initial hypothesis was that contamination had somehow reached the annular spaces of Wells W and X through the natural drainage courses. Shallow subsurface cross-sections were drawn, pump tests of recovery wells were completed and recovery well yields were measured to determine the pathways for horizontal and vertical migration. Soil sample head-space analysis with an organic vapor analyzer (in combination with subsequent analytic testing) was used to map the extent of the contamination.

With the construction of Recovery Wells J-O, a major pathway was identified. Completion of the cross-sections (Fig. 2), along with analysis of soil samples, revealed a continuous silt lens extending below the plant site from approximately 40-65 ft below grade. Free phase contamination entered the lens through direct vertical migration from a large ponding area and by moving through spaces around pilings under a nearby, abandoned foundation. Free phase contamination then migrated downgradient to the annular spaces of Wells W and X. A similar phenomenon apparently occurred in a separate plant area with resulting contamination moving to Well Z.

Borings in the vicinity of Wells Z, X and W revealed that the contamination has moved down the annular spaces and thence horizontally through deeper permeable zones such as those at 120, 190 and 250 ft. Shallow recovery wells were constructed throughout the affected zone, and deep recovery wells have been installed near Wells W, X and Z.

The typical design of a recovery well is shown in Figure 3. Jet pumps with eductors were utilized due to the low well yields (less than 5 gal/min) and the presence of free phase organic solvents. Early operations were hampered due to emulsification, pump breakdowns and problems in coordinating maintenance work. Use of polymers has reduced emulsification and, in turn, pump breakdown problems. On the average, each well is capable of producing 3000 gal/day. Each well is pumped 8 to 12 hr per day and then allowed to recover. Pump tests indicated that, generally, a well spacing of 100 ft would result in maximum short term recovery. Some wells asre currently yielding as much as 5% free phase organics, a decrease of 20 to 30% from the initial well recoveries.

The recovered fluids are pumped to separation tanks and the free phase organic portion is recycled to the plant. The waste water is transported to a stripper column and subsequently discharged in the plant wastewater system.

As contaminated fluids in the immediate vicinity of a recovery well are withdrawn, the fluid is replaced by a combination of: (1)
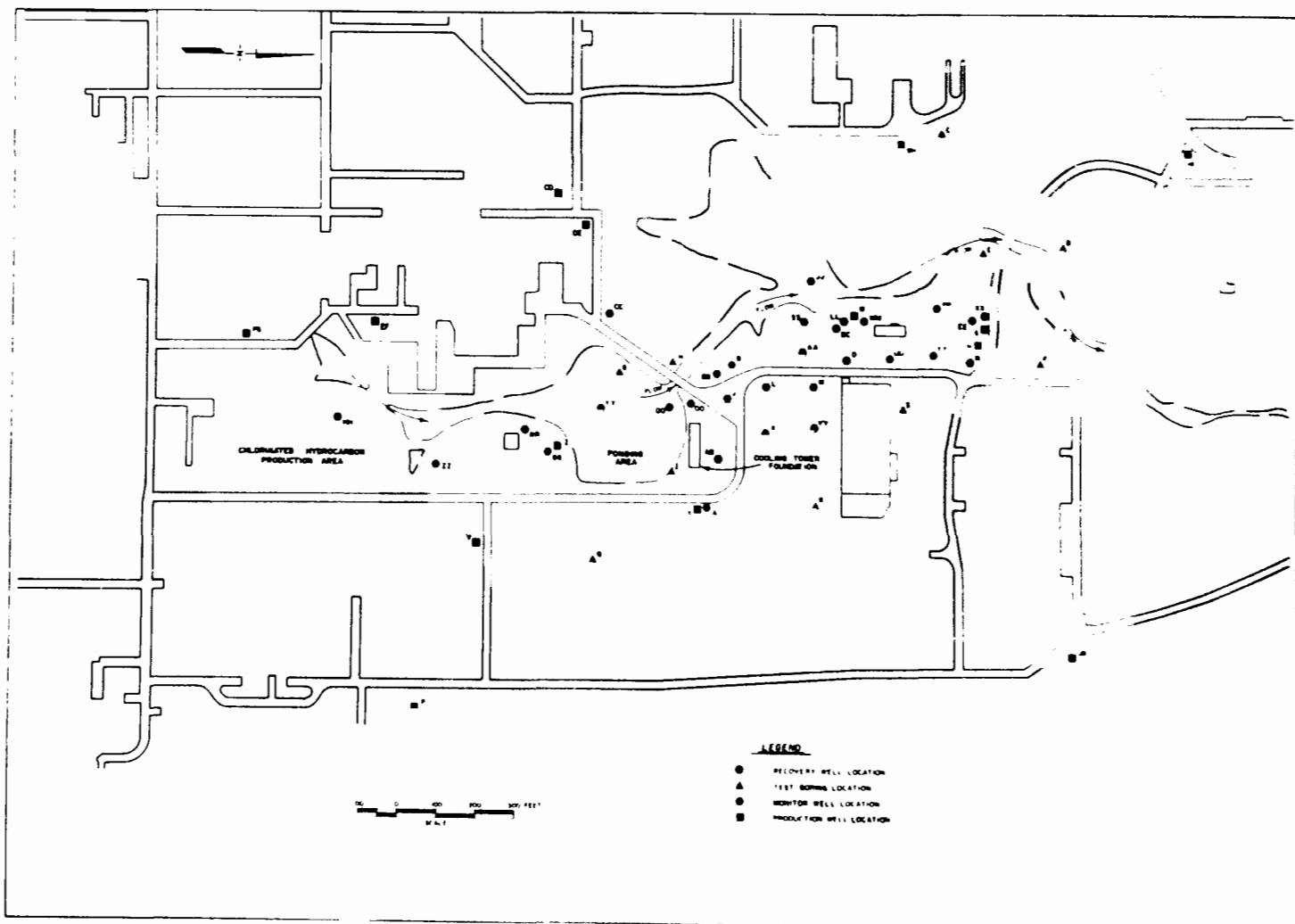
Figure 1
Chemical Plant Layout and Location of Monitoring Wells
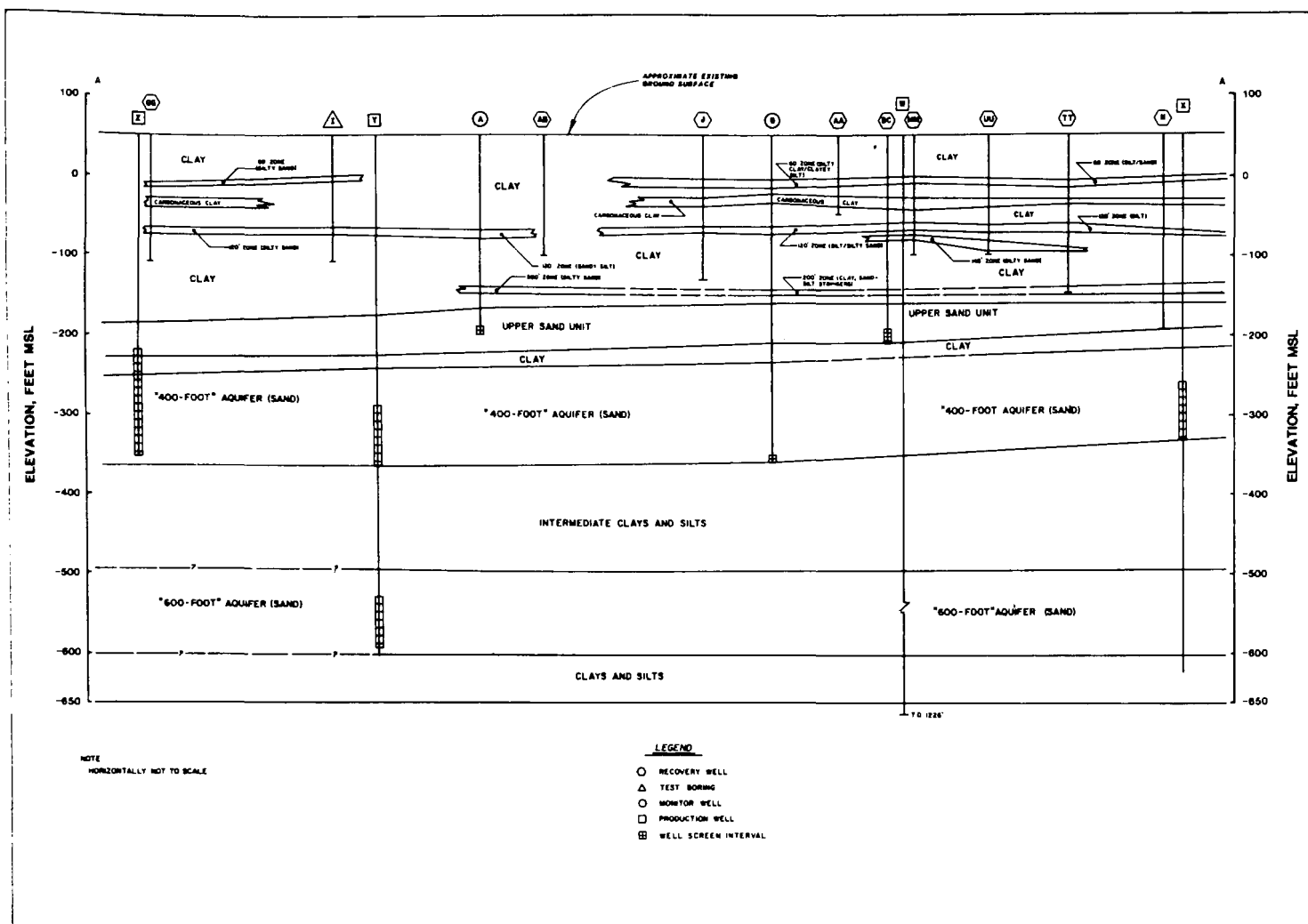
Figure 2
Geological Cross-Section Below the Plant Site

heavier than water contaminants being drawn horizontally toward the well and (2) relatively clean water being drawn from the above more permeable portion of the silty zone. Consequently, recovery yields will decrease with time. The rate at which they will be removed is a function of the horizontal pore velocity. The horizontal pore velocity at a given distance is equal to permeability times the gradient at that distance.

The permeability of the silt zone varies widely. The zone is a distinct formation which probably has a permeability two to three orders of magnitude higher than the overlying and underlying clays. The zone itself, however, is heterogeneous, ranging from silty clay to medium grained sand. Permeabilities probably range from 10^{-3} to 10^{-6} cm/sec. This lithology is a result of a complex depositional environment. A degree of continuity for some of the clay, silt and sand lenses can be assumed. The underlying clay is relatively continuous and has a tested permeability of about 1 X 10^{-8} cm/sec.

Most of the contamination pooled in the sandy-silt lenses and subsequently migrated along pathways dictated by the slope of the underlying clay and the regional (southward) gradient. The fact that the contaminants moved from the ponding area to Well X (1000 ft) in less than 20 years, at gradients of 1%, indicates that there is an average permeability, for some of the lenses, of at least 10 ft/day (10^{-3} cm/sec).

Most of the free phase contaminants will therefore be removed from the sandy lenses at fairly high velocities. Assuming an average permeability of 10^{-3} cm/sec for the sandy lenses, these lenses can be "cleaned" within a radius of 50 to 100 ft in one to three years.

It was estimated that, during a period of up to three years, most of the additional free phase organics that can be recovered (about 35% of total mass) will be removed from the adjacent silts.

The recharge of clean water (for the long term removal of concentrations) will flush the lenses to levels which pose even less risk of eventual migration into the underlying aquifers.

WELL PLUGGING

To reduce the risk of contamination to the underlying aquifers, the annular spaces of all abandoned water-supply wells in the potentially contaminated areas were plugged. Generally, the casing of these wells had been sealed with substantial surface and aquifer-level plugs. Only in recently constructed wells had the entire casing been grouted. As evident from the intermittent contamination found at depths of about 120, 140 and 250 ft, organics were migrating from the upper source, down through the annular space along the less tortuous path presented by the casing.

Slant hole drilling into the annular space at a depth of about 70 ft was completed and grout injected until a surface return had been achieved. Continued water well pumping in combination with the well plugging program has resulted in a 90% decrease in maximum aquifer contaminant concentrations. Nonetheless, computer modeling and field data demonstrate that while the primary source has been substantially reduced, the presence of contamination at 120, 140 and 250 ft near the wells constitutes a continuing source for migration around the grout until the recovery program is complete.

AQUIFER MODELING

D'Appolonia emplolyed GEOFLOW, an in-house computer software package, to simulate groundwater flow and contaminant movement within the underlying aquifers. Contaminant concentrations in the 250 to 400-ft aquifer approach 10 ppm EDC while levels in the 500 to 600-ft aquifer are less than 100 μg/l EDC. Thus, contaminant migration modeling was focused on the 400-ft aquifer.

GEOFLOW is a finite element grid program which idealizes groundwater flow into a two-dimensional system. This assumption is valid where variations in aquifer thickness are much less than total thickness. In the modeling, the aquifer was also assumed to be homogeneous, isotropic and of infinite areal extent. Additional data were developed through literature search and water-supply well testing to define variations in aquifer thickness, permeability, storage coefficient, effective porosity, elevation and the retardation (attenuation) factors of the aquifer for the contaminants of concern.

The available data from agencies and nearby plant wells were organized for input into the models of the 400- and 600-ft aquifers. Interpretation was based on maps and tables which included well and boring location maps, isopach maps, structure maps (elevations of formations), potentiometric surface maps, geologic cross-sections, water elevation versus time graphs, field permeability test result tables and well pumping rate summaries.

A finite element grid system incorporating the plant and the neighboring plants was generated. Each element of the grid system represented a discrete segment of the aquifer and was assigned values for aquifer thickness, permeability, storage coefficient, effective porosity and elevation.

Groundwater flow within the aquifers is primarily a function of three parameters:
• Well locations
• Pumping rates
• The recharge (boundary conditions) at the periphery of the area modeled

Sensitivity analyses were performed to assure that the modeling results would be representative of real conditions. GEOFLOW was utilized to solve the governing equations and thereby simulate flow and contaminant movement at the plant site. Initial modeling confirmed the need to incorporate the complex geology of a greater
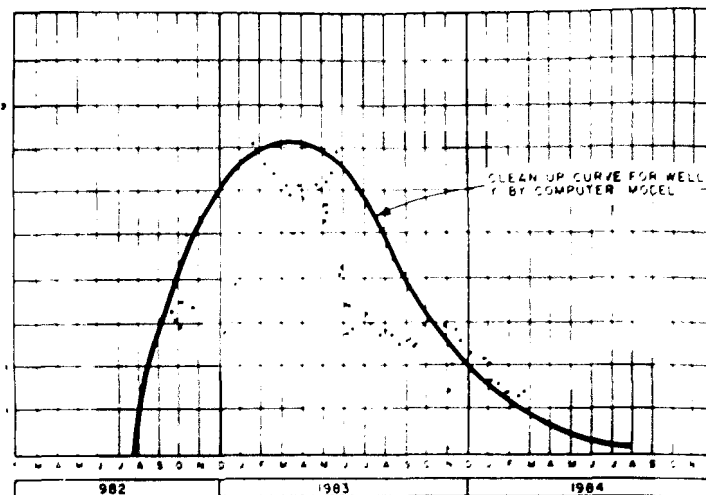
Figure 4
Simulated Clean-Up Curve

area inclusive of the hydrogeological regime below the Mississippi River to simulate the hydrogeologic setting of the industrial area surrounding the plant. The grid system for later mass transport simulations was essentially the interior portion of the larger flow grid system with constant flow boundaries.

Quality control and quality assurance checks of the input data against the raw data were performed to eliminate errors and to assure that modeling was based on the best available data.

Several simulations, representing different sets of pumping rates, were performed for both the 400 and 600-ft aquifers. The two critical scenarios were:
• *Historical Case*—Under historic operating conditions, regional groundwater flow within the 400-ft aquifer is toward the plant from all directions and is controlled by pumping.
• *Worst Case for Plume Containment*—The worse case analysis predicted groundwater movement through the plant to the southeast in the unlikely event of the plant's pumping wells being totally inactive and the pumping of nearby wells being at full capacity.

Three additional 400-ft aquifer simulations were performed to illustrate the effects of alternative scenarios for the pumping of nearby wells. Additional modeling for the 400-ft aquifer was completed to determine whether adjusting the distribution among plant well pumpages would affect the regional gradient toward the plant site or the downward gradient between the shallow contaminated zones and the 400-ft aquifer. These simulations were also conducted to identify the optimal location of a new production well. The conclusions reached as a result of the flow simulations were:
• On-site contaminant plume control in the 400-ft aquifer can be maintained even with significant reductions in pumping (50% reduction at Well Y; elimination of pumping at Well P).
• Under typical plant pumpage from the 400-ft aquifer, 1900 gal/min, variations in pumpage distributions do not significantly affect the overall groundwater flow pattern toward the plant. The primary change is limited to the area encompassed by the radius of influence of the well.
• The vertical gradient is increased significantly only within a few feet of the pumping well. Accordingly, vertical migration is probably limited to near the wells.

Similar conclusions were drawn from the 600-ft aquifer simulation. Based upon these findings, two general locations for a new water supply well, Well V, were recommended. In addition, Wells W (now abandoned), X and perhaps Z were confirmed as potential vertical pathways to the underlying aquifers.

CONTAMINANT MIGRATION MODELING

GEOFLOW was used to evaluate the potential source(s) of organics contamination in the 400-ft aquifer. Potential combina-
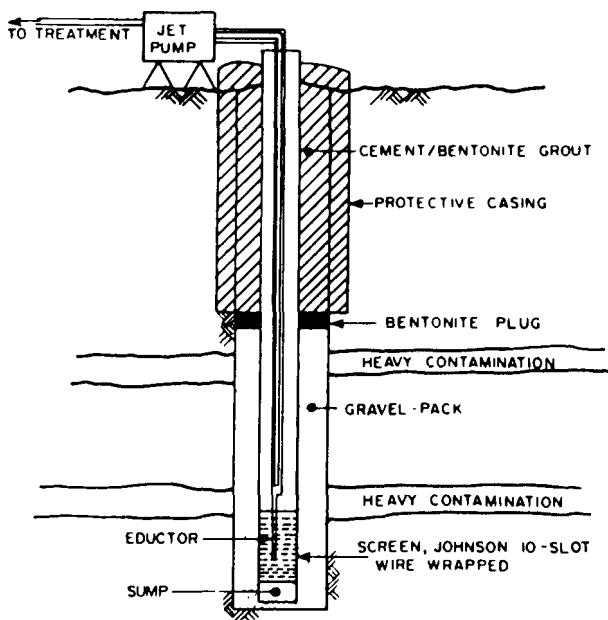
Figure 3
Typical Organic Recovery Well

tions of contaminant source locations and historical pumping rates that may have produced the existing distribution of organics in the 400-ft aquifer were evaluated to assess the likelihood of each particular source. The basis for determining the validity of a transport simulation result, relative to existing conditions, was the degree of correlation with water quality data for various wells (water wells, recovery wells and observation wells) obtained during the previous months. For example, transport modeling was undertaken to test which of the two locations, Well W or X, was the more predominant source.

The results from modeling a three year active leak were compared with the groundwater chemical analyses. A constant dimensionless concentration of 1.0 was used for the contamination source.

The simulation results illustrated the following features:
• For either source, the primary direction of the model plume movement was from the source area toward Well Y. The plume also spread normal to the direction of flow due to hydrodynamic dispersion.
• For either source, Well Y intercepts most of the contamination.
• Once organics are introduced in the aquifer, their presence is observed at Well Y in a period of less than six months. The concentrations reached approximate steady-state conditions within 1 to 2 years.

Calculations were made comparing the computed concentrations to observed ones and two conclusions became apparent:
• Well X was not the dominant source. Even though computed concentrations at Well Y were comparable to observed levels, the computed concentrations at Well X were orders of magnitude higher than those actually observed.
• The computed ratios of concentrations for Wells Y and Z, with W as the source, were consistent with the observed ratio.

Subsequent additional field evidence supported the conclusion that W was the dominant source. In particular, the simulated cleanup curves at Well Y for a W source are very much like the observed data (Fig. 4).

In addition, comparison of contaminant constituent ratios (EDC, perchloroethylene, trichloroethylene) for different recovery wells showed that the ratios from Wells Y and Z were comparable to the ratios found in recovery wells near Well W and unlike those for wells near Well X.

REMEDIAL ACTIONS

The cleanup of the 400-ft aquifer is a function of the geographical dispersion of the higher concentrations of contamination and of desorption rates. Contaminants primarily disperse longitudinally with the gradient. However, they also disperse, to a lesser degree, transverse to the gradient. Cleanup occurs as contamination is washed off of the soil grains, i.e., desorbed. The higher the concentrations, the longer the period to clean up to a certain level. The key then to rapid cleanup is to prevent transverse dispersion from increasing the areal extent of contamination. Consequently, alternative pumping programs were evaluated to develop the most effective pumping protocol.

The amount of water required to remove contamination from the 400-ft aquifer was the subject of laboratory desorption tests by D'Appolonia. A sand sample from the 400-ft aquifer was packed to a 32% porosity (approximately 20% effective porosity) in a column with a flexible wall. The column was flushed with a solution containing 20 mg/l EDC and lesser concentrations of other chlorinated hydrocarbons. Afterwards the column was flushed with distilled water and the desorption rate for the various hydrocarbons was observed.

A 95% reduction in EDC concentration (from 20 ppm to 1 mg/l) can be accomplished with 3.5 pore volumes of flushing. Estimates involving the pore velocity between Wells W and Y showed that 3.5 pore volumes corresponded to time periods of about three years. Since clean water does not actually flush the zones of higher concentration, (the groundwater becomes more contaminated as it moves toward the pumping well), the real time required to reduce concentrations below 1 mg/l could be slightly longer.

It was concluded, through the analysis of modeling, pumpage and chemistry data, that the contaminant plume is small and is being rapidly removed at Well Y. These conclusions supported the choice of the following remedial actions:
• Continued pumping of Well Y at its maximum rate
• Continued pumping of Wells Z, X, V and existing deep recovery wells
• Additional drilling and recovery from deeper zones near Well Z and annular "space" grouting

Cleanup of the 400-ft aquifer to concentrations less than 1 mg/l was projected within 3 years. Even lower concentrations will depend on the success of the well annulus plugging program and shallow organics recovery program. Analysis of future chemistry and pumpage data, and possible further modeling, is important to confirm and refine the above conclusions.

CONCLUSIONS

The foregoing study demonstrates the efficiency of a combined investigation/remedial program and the success of the approach followed. A thorough hydrogeologic assessment, with painstaking data gathering and careful analysis, was the crucial first step. Key to recent reductions in the contaminant concentrations in the underlying aquifers was the quick implementation of remedial measures to:
• Remove the source contamination (shallow recovery wells)
• Inhibit source migration (well plugging)
• Control plume migration (designed water supply well pumping program)

Consequently, the plume has been controlled before it has dispersed significantly, and an adequate conceptual model of the situation has been developed. Neither would have been possible without the timely input and interpretation of results from the recovery well and modeling investigation program.

The overall approach was successful because it represented a comprehensive cost-effective effort to collect and analyze readily obtainable data in a timely manner. Of particular importance were:
• Development of an early understanding of regional aquifer characteristics
• Detailed analysis of previous plant geotechnical boring logs
• Field mapping of soil contaminant levels with an organic vapor analyzer
• Organizing and interpreting chemical analyses and pumping records for the recovery and water supply wells
• Formulating, scrutinizing and refining hypotheses regarding potential sources and quantities of contaminants, and migration pathways
• Mass transport/dispersion modeling as well as hydraulic modeling coupled with a flexible field program to develop calibrating and corroborating data
• Implementation of a management plan to concentrate efforts on the problem at hand, i.e., generating a successful remedial program for the plant and the aquifer

DETERMINING CONTAMINANT MIGRATION PATHWAYS IN FRACTURED BEDROCK

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INTRODUCTION

The deep bedrock well which supplies water to an apartment complex was found to be contaminated during a hazardous waste site investigation. This apartment complex (195 units) and 18 homes are situated on 200 acres of developed land in Southern New Hampshire.

The investigation revealed widespread contamination of the bedrock aquifer with volatile organic compounds. The predominant compounds found in the ground water include: 1,1-dichloroethane, trans 1,2-dichloroethylene, ethylbenzene, trichloroethylene and toluene. The source area for the contamination that migrated to the apartment complex water supply well was approximately 1,500 ft away in a sparsely wooded area (Fig. 1).

PHYSICAL SETTING

The study area is characterized by the low rolling hills of the glacial terrain common throughout southern New England. The major drainage basin for the area is the Merrimack River. A tributary to the Merrimack is the surface drainage for the site. The land surface of the site has a 4% slope to the southwest.

The hills surrounding the area rise from 100 to 200 ft above the valleys. Within a 1 mile radius of the site, the highest elevation is 460 ft above MSL and the lowest is 220 ft above MSL.

The homes in the study area use septic tank leach field systems for disposal of their household wastewater. Prior to the discovery of the contamination and the subsequent construction of a water line, the residents did not have access to a municipal water supply. Throughout the area, the majority of residents rely on deep bedrock wells to supply their homes with water.

STUDY OBJECTIVES

The major objectives for this investigation were the following:
- To establish the source(s) and aerial extent of contamination
- To identify the contaminants and their concentrations throughout the study area
- To determine contaminant migration pathways within the bedrock
- To assess the hydraulic conductivity of the bedrock aquifer

These objectives were attained by the completion of a field investigation which included an air photo analysis, a fracture trace analysis, a seismic refraction survey, the installation of monitoring wells and a pump test of the water supply well serving the apartment complex. The results of this investigation are discussed in this paper.

GEOLOGIC SETTING

Bedrock Geology

There have been several studies of the bedrock of the Manchester quadrangle. The rocks of the area were named, dated and described on the State of New Hampshire Bedrock Geology Map[1] and the detailed bedrock map of the Manchester quadrangle.[2] A bedrock fracture trace analysis was conducted in Londonderry in 1981. The most recent studies are being contracted by the Nuclear Regulatory Commission.[3]

The regional trend of the bedrock is northeast. Much of the rock in the area has been intensely folded with northeast southwest trending fold axes. The site lies on the southeastern flank of the Merrimack synclinorium.

Billings[1] mapped the bedrock in the study area as part of the Merrimack group of meta-sedimentary rocks. Sriramadas[2] broke the Merrimack group into two major subdivisions; the Berwick and Elliot formations. The Berwick formation underlies the study area.

The stratigraphic units present at the site can be traced continuously from eastern Connecticut to southern Maine[4] (Fig. 2).
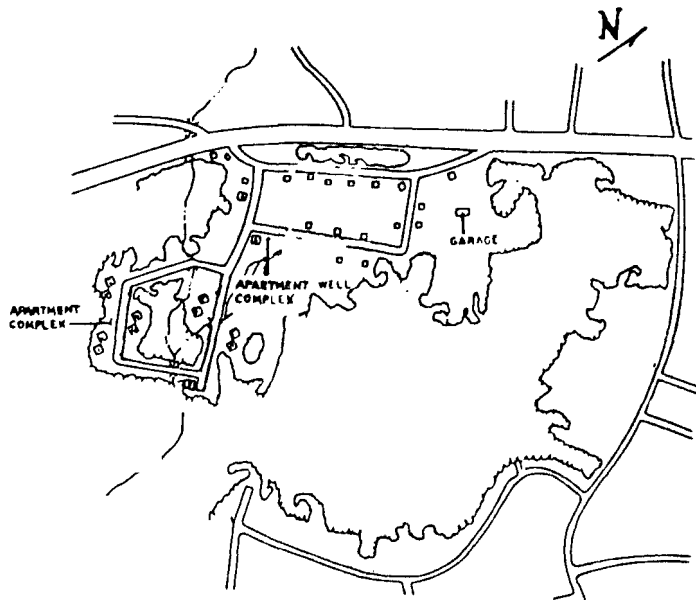
Figure 1
Area of Groundwater Contamination Study[1]
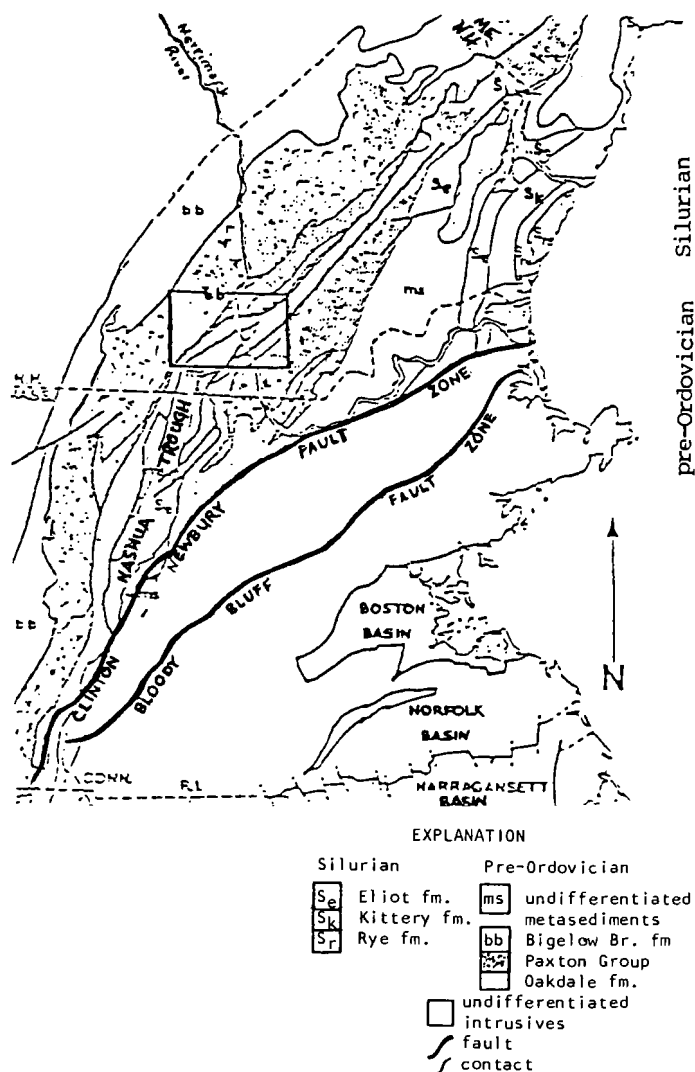
Figure 2
Map Showing Generalized Geologic Structure of Southeastern
New Hampshire and Adjacent Maine and Massachusetts
(after Barosh and Moore, in prep.)

EXPLANATION

Silurian

S_e	Eliot fm.
S_k	Kittery fm.
S_r	Rye fm.

Pre-Ordovician

| ms | undifferentiated metasediments |
| bb | Bigelow Br. fm Paxton Group Oakdale fm. |

☐ undifferentiated intrusives

⟋ fault

⟋ contact

Barosh, in recent detailed studies, has named and dated these formations. The lower member of the Berwick formation corresponds to the Paxton group. Recent age dating places these rocks as pre-Ordovician. In 1953 and 1954, Billings and Thompson noted the similarities between the lower member of the Berwick formation and the Oakdale formation seen in Central Massachusetts.

A major structural feature in the area is the Nashua trough, a zone of numerous faults of the Paleozoic epoch.[4] One of these faults that appears to run through the study area is called the Nashua fault (Fig. 3). The fault in this area is concealed by thick glacial deposits. To the northwest of the fault are the older, highly metamorphosed strata of the Oakdale formation which border the younger, low to moderately metamorphosed strata of the Paxton group.[3] It is a northeast trending fault which dips steeply to the northwest. It is described as a high angle, right lateral, reverse fault.

The Oakdale formation consists of metasiltstones, phyllites and sillimanite becoming garnet schists. The Paxton group is composed of chlorite-grade, gray metasiltstones, phyllites and minor amounts of calcareous metasiltstones.[5] Numerous intrusions of quartz monzonite, granite, granodiorite and pegmatites have been found throughout the area.[3]

The integrity of the bedrock beneath the site was investigated with borings and by a seismic refraction survey. The bedrock was highly weathered and fractured throughout most of the study area. The bedrock has been affected by both the large scale geologic processes, which caused the metamorphism and deformation of the rocks, and smaller scale occurrences such as faulting. In addition, the Berwick formation is brittle in nature and glaciation has added to the fracturing and caused substantial weathering of the bedrock.

A study of the bedrock fracturing just north of the study area shows predominant northeast and northwest fracture orientations. At an outcrop in a road cut one mile north of the site, the majority of fractures had a strike of N45E and a dip of 60° NW. In a fracture study by Ecology and Environment, Inc., geologists produced a stereographic plot of the poles of 165 fractures. The majority of the fractures had a N57E orientation.

The elevation of the top of bedrock above MSL is shown on Figure 4. The contours which are not in the boldprint are land surface elevations above MSL (Refer to Fig. 3). The general slope of the rock is in a southeasterly direction with a 4% slope.

If the surficial deposits on the site are heterogenous, hydraulic conductivities vary from place to place. Although the sediments on this site are primarily glacial stream and alluvial deposits, they contain a mixture of grain sizes. Sizes range from coarse to fine sands with traces of gravel and silt. In addition, the till contains cobble size materials and clay.

Groundwater Hydrogeology

Unfractured schist has a low hydraulic conductivity (1×10^{-6} cm/sec and less). Schistose rocks contain planes of weakness paralleling foliation which promotes fracturing and erosion. Thus zones of higher conductivity often lie parallel to the foliation. The foliation trends northeast and dips steeply to the northwest in the site area. Fractures, joints and other discontinuities provide pathways for groundwater flow. This became apparent during the drilling. The unconsolidated aquifer was found to be in good hydraulic communication with the bedrock aquifer. The rock is highly weathered in some areas. This leaves an extensive void space for the groundwater to fill.

The predicted groundwater flow direction in the unconsolidated aquifer is to the south and southeast. The flow direction is strongly influenced by the bedrock topography of the site. The recharge areas lie to the north of the site. The major discharge zones are a tributary to the Merrimack River and the swamps bordering it.

Water Levels and Gradients

Data from the 31 monitoring wells are presented in Table 1. These data include total depth, depth to bedrock and water level elevations. Cluster wells have the deeper well designated by the well number, e.g., wells 10 to 10D.

A contour map of the water table elevations in the shallow bedrock wells is presented in Figure 5.

The flow gradients are southeast in the area behind the garage and south for the remainder of the site. The upper 15 ft of bedrock are fractured and weathered over a large portion of the study area. This condition allows good hydraulic communication with the overlying glacial deposits. Therefore, using equal head contour lines, flow direction can be approximated in the shallow bedrock aquifer. However, this is not possible in the deep, bedrock wells.

FRACTURE HYDROGEOLOGY

Many papers have been written about the study of fluid movement through porous media. This is not the case with fracture hydrogeology. Little attention has been given to this field because of the lack of economic incentive and the extreme complexity of the problem.

One of the first major experiments in fracture hydrogeology was conducted on artificial fractures.[7] A comprehensive review of literature in this field[8] indicates there is little agreement on the accuracy of the existing models for flow in fractured media.

The majority of crystalline and sedimentary rock masses consist of rock blocks bounded by discrete fracture planes.[9] The study area consists of a metasedimentary schist with low porosity and

Key

Rock Units

Quartz Monzanite
A metamorphosed sandstone

Pm Paxton Group
Consists of gray metasiltstones, chlorite grade phyllite
and minor amounts of calcareous metasiltstone

Od Oakdale Formation
Consists of metasiltstones, phyllite, and garnet sillimanite
schist

Inferred contact

▲ ▲ ▲ ▲ Inferred fault trace
High angle thrust fault
▲ ▲ point to the up thrust side

Figure 3
Bedrock Map

permeability. Since the hydraulic conductivity is estimated to be between 1×10^{-2} and 1×10^{-7} (cm/sec), flow through the rock itself would be insignificant. Thus, the major flow must occur via secondary porosity. The pathways for groundwater flow and contaminant migration in bedrock to be considered are joints, fracture zones and shear zones. The flow through these discontinuities is controlled by the orientation, interconnection and spacing of these linear features. To adequately address the directional permeability of the rock mass, all of the above characteristics must be considered.

Joints can be considered effective pathways if their ratio of length to joint spacing is large. If they are interconnected, they form a potential flow network. The extent of interconnection is dependent upon the orientation of and length of the different joint sets.

Fracture zones may consist of closely spaced, highly interconnected fractures which have remained open. These fracture zones are an aggregate of fracture sets. A fracture set can be defined as a number of fractures having the same or closely shared orientations. Fracture sets can be identified by plotting the poles of the individual fracture planes on a steronet. The resulting plot indicates the orientations of the various fracture sets. Recent studies have found that fracture orientations measured on the surface (i.e., outcrops) have similar orientations to those in the subsurface.[10,11] Permeability is also determined by the degree of interconnection of fractures and the distribution of the fracture aperatures.

The principles of flow and permeability of fractures are of great importance. The primary fracture characteristic is the size of the aperature which exerts a major influence on flow. The aperature of the fracture cubed is proportional to the flow through a unit length

⌃ Elevations of surface
— Top of bedrock above MSL
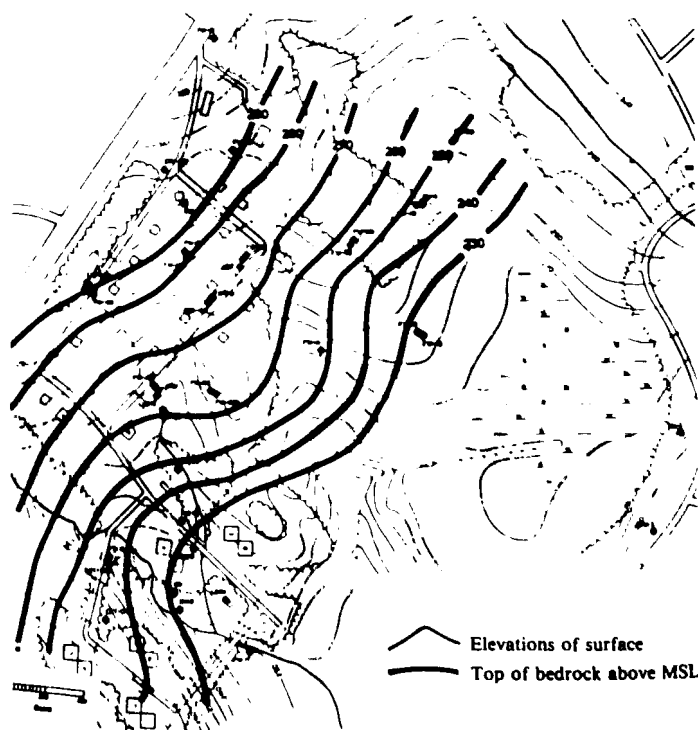
Figure 4
Bedrock Elevations
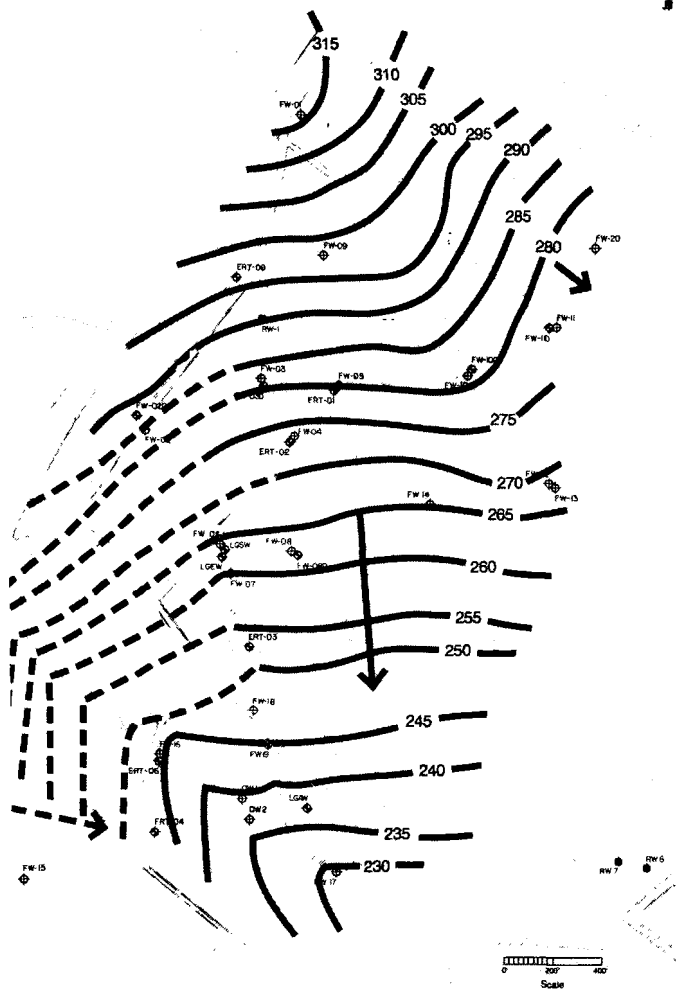
Key

● RW2	Residential Well		Water level elevations above MSL in shallow bedrock—data from wells less than 50 feet into bedrock
⊕ FW3	Field Investigation Team (Shallow Well)*	280	
⬒ FW4	Field Investigation Team (Deep Well)**	280	Inferred water level elevation above MSL in shallow bedrock
⬒ ERT5	Emergency Response Team Deep Well	*Shallow Wells	Consist of an open borehole in bedrock up to 50 feet into rock
⬒ LGSW	Londonderry Green Supply Well		
⬒ LGAW	Londonderry Green Abandoned Well	**Deep Wells	Consist of an open borehole in bedrock from 100 feet to 300 feet into rock
⬒ LGEW	Londonderry Green Emergency Well	←	Direction of flow potential

Figure 5
Water Level Elevation Map

tion."[9] As stress increases, hydraulic conductivity decreases. It is thought that interconnections and fracture aperature decrease with increases in stress which, in turn, reduces hydraulic conductivity.

Pump Test

Evidence supporting the theory that contaminant migration is fracture controlled in the study area was gathered during the groundwater study. After analyzing the results of the groundwater sampling and mapping the oddly shaped plume of contamination, a pump test was initiated.

A 68-hr pumping test was conducted at the site on Aug. 9, 1983, and water level elevations were recorded in all the wells for the duration of the test. The apartment complex supply well was the pumping well, and a discharge rate of 20 gal/min was continuous for the entire test.

Flow Conditions in Fractured Rocks

A pump test in an unconfined homogeneous aquifer causes a symmetrical cone of depression in the surrounding aquifer. The flow lines converge on the well from all directions, and drawdown decreases with distance from the pumped well.

The results of a pump test in fractured bedrock are very different. When a well which intersects a fracture is pumped, the water level in this fracture is drawn down. Continued pumping induces movement of the water into the fracture from other, interconnected fractures within the aquifer. The pumped fracture acts much like a collector well. The drawdown is not radial but is a trough-like depression parallel to the pumped fracture (collector well), as shown in Figure 6. Radial flow equations do not appropriately apply to pumped fracture drawdown data.[14]

When plotting pumping test data where linear flow is suspected, a semi-log of drawdown(s) versus time(t) is not appropriate. The use of a semi-log plot of drawdown(s) vs. time(t) will result in a curvilinear plot. This indicates that the traditional methods of aquifer test analysis are not applicable since the aquifer is extremely

of the fracture. This relationship explains how a few major fractures can dominate the entire flow system.

Fracture intensity (degree of fracturing) has a strong effect on the directional permeability of the rock mass. The orientation and spacing of fracture sets define the fracture intensity. A similar orientation among a major portion of the fracture sets will show an increased permeability in that direction. Directional permeability is not geometrically related to lithologic boundaries in a frequently anisotropic fractured rock flow network.[12] Shear has been studied the least although it has a great effect on permeability.[13] The hydraulic characteristics of fractured rock masses and the relation to stress and depth should be considered. As depth and stress increase, hydraulic conductivity decreases in a linear fashion. "Although it is assumed that stress and fracture interconnection may be the two most important variables controlling flow through fractured rocks, no quantitative data exist to verify this assump-

Figure 6
Conceptual Model of a Linear Flow System[14]

Table 1
Water Level Readings During Pump Test
(Measured in feet to top of casing, TOC)

ELAPSED TIME

Well Numbers	O Hours TOC	O Hours Elevation	24 Hours TOC	24 Hours Elevation	48 Hours TOC	48 Hours Elevation	68 Hours TOC	68 Hours Elevation	Total Drawdown
FW-01	9.9	317.65	NM	NM	10.1	317.45	NM	NM	0.2
FW-02	6.1	288.77	6.5	288.37	6.3	288.57	6.3	288.57	0.2
FW-02D	7.4	289.78	7.8	289.38	7.7	289.48	7.8	289.38	0.4
FW-03	8.4	283.49	8.8	283.09	8.6	283.29	8.8	283.09	0.4
FW-03D	10.1	281.05	11.8	279.35	11.5	279.65	12.0	279.15	1.9
FW-04	7.5	275.86	10.8	280.35	10.4	280.75	10.8	280.35	3.3
FW-05	6.4	280.03	7.6	278.83	7.6	278.83	7.3	279.13	0.9
FW-06	10.7	260.21	11.1	259.81	11.5	259.41	11.7	259.21	1.0
FW-07	3.5	258.51	3.5	258.51	3.5	258.51	3.6	258.41	0.1
FW-08	11.4	262.13	14.6	258.93	15.4	258.13	15.5	258.03	4.1
FW-08D	11.2	262.93	33.4	240.73	37.3	236.83	37.9	236.23	26.7
FW-09	10.3	296.74	10.6	296.44	10.6	296.44	10.7	296.34	0.4
FW-10	8.8	282.29	9.1	281.99	9.3	281.79	9.3	281.79	0.5
FW-10D	24.6	267.76	50.2	242.16	56.7	235.66	57.8	234.56	33.2
FW-11	6.9	275.67	7.2	275.37	7.4	275.17	7.3	275.27	0.4
FW-11D	14.6	268.22	40.0	242.82	42.6	240.22	43.6	239.22	29.0
FW-12	11.3	268.03	13.1	266.23	14.2	265.13	14.5	264.83	3.2
FW-13	10.7	268.78	11.0	268.48	11.0	268.48	11.0	268.48	0.3
FW-14	8.1	264.20	16.9	255.40	19.6	252.70	20.0	252.30	11.9
FW-15	15.1	269.03	15.2	268.93	15.4	268.73	15.3	268.83	0.2
FW-16	8.1	246.69	8.3	246.49	8.2	246.59	8.3	246.49	0.2
FW-17	3.9	229.34	4.0	229.24	3.9	229.34	3.9	229.34	0.0
FW-18	7.1	246.51	7.2	246.41	7.2	246.41	7.2	246.41	0.1
FW-19	5.0	244.06	5.0	244.06	4.9	244.16	4.6	244.46	-0.4
FW-20	6.1	275.00	6.7	274.40	6.9	274.20	7.0	274.10	0.9
ERT-01	2.7	281.64	3.8	280.54	3.3	281.04	3.5	280.84	0.8
ERT-02	6.3	278.04	9.5	274.84	9.2	275.14	9.6	274.74	3.3
ERT-03	2.8	254.55	3.0	254.35	3.6	253.75	3.7	253.65	0.9
ERT-04	17.9	248.84	18.1	248.64	18.1	248.64	18.1	248.64	0.2
ERT-06	7.1	247.36	7.2	247.26	7.3	247.16	7.2	247.26	0.1
ERT-08	8.7	298.08	9.1	297.68	8.8	297.98	8.8	297.98	0.1
LGSW	2.1	266.57	54.6	214.07	57.0	211.67	57.6	211.07	55.5
LGEW	Artesian	>266.43	46.2	220.23	48.7	217.73	49.4	217.03	>49.4
LGAW	Artesian	>246.73	Artesian	>246.73	Artesian	>246.73	Artesian	>246.73	0.0

Pumping Well: LGSW
Starting Time 1600 hours
Starting Date: August 9, 1983
Discharge, Gallons per Minute (GPM): 20

NOTES:
NM - Not Measured
Rain began at approximately 0900 hours on Aug. 11, 1983 (41 hours elapsed time) and continued through the end of the pump test. Approximately 1.25 inches of precipitation fell during this time which may have caused water levels to rise in some wells, particularly in shallow wells, during this time period.
See Figure G-2 for locations
From draft NUS Report, 16

anisostropic. A plot of drawndown(s) vs. time(t) on arithmetic graph paper will result in a straight line indicating that drawdown vs. time is a linear relationship. Drawdown occurs as a "trough" of depression, suggesting linear flow in fractured rock.[14]

Drawdown was greatest in wells closest to the fracture (collector well) and was not dependent upon the distance from the pumping well. That is, the well closest to the pumped well may not be the well closest to the fracture collector well.

Drawdown data from two observation wells on the same side of a fracture can be used to determine two possible orientations of the fracture[14] (Fig. 7). Field data can then be used to support the most probable orientation.
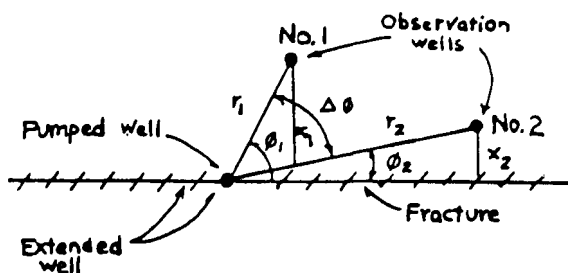
Figure 7
Comparison of Radius (r) from a Pumping Well and Distance (x) from an Extended Well in an Idealized Aquifer.[14]

The equation developed[14] was used to calculate drawdown at any perpendicular distance, x, from the fracture at any time, t, after pumping. A first order McLaurin expansion performed to simplify the results and adapt them to an arithmetic plot of drawdown (s) vs. time(t) yields the equation:[14]

$$\frac{T}{S} = \frac{\Pi X^2}{4 t_0} \tag{1}$$

In this equation: t_0 = time 0, the value of $(2\sqrt{t})$ or t at the line of zero drawdown; S = storage coefficient; T = the transmissivity; X = the perpendicular distance in feet from the fracture of extended well from equation (1).

The plotted data of each observation well is displaced from the origin along the $\sqrt{t}$ axis according to the hydraulic diffusivity of the system and the perpendicular distance from the pumped well.

The radii from the pumping well and the angle between the two observation wells can be measured in the field (Fig. 7). The unknowns are the two perpendicular distances (X1, X2) from the fracture and the angles between the radii (R1, R2) and the fracture. These values can be determined using the following equations:

$$X1 = R1 \sin \phi1 \tag{2}$$

$$X2 = R2 \sin \phi2 \tag{3}$$

$$\Delta\phi = \phi1 - \phi2 \tag{4}$$

As discussed earlier, drawdown is proportional to the distance from the fracture surface. Therefore:

$$\frac{t_{o1}}{X1} = \frac{t_{o2}}{X2} \tag{5}$$

$$\text{and } \frac{X2}{X1} = \frac{t_{o2}}{t_{o1}} = \frac{R2 \, Sin \, \emptyset2}{R1 \, Sin \, \emptyset1} \tag{6}$$

$$\text{Solving for } \emptyset2: \quad \emptyset2 = Tan\text{-}1 \left[\frac{R1 \sqrt{t_{o2}}}{R2 \ t_{o1} - R1 \ t_{o2} \ cos \, \triangle\emptyset} \right] \tag{7}$$

$$\text{and } \emptyset1 \quad \emptyset2 + \triangle\emptyset \tag{7}$$

Then X1 and X2 are obtained from equation (2, 3 and 4), and Equation 7 becomes:

$$\emptyset2 \quad tan\text{-}1 \left[\frac{R1 \ t_{o2} \ Sin \, \triangle\emptyset}{R1v \ t_{o2} \ Cos \, \triangle\emptyset - R \ 2\sqrt{t_{o1}}} \right] \tag{8}$$

Data from wells 8D and 10D were used in the above equations. The observation wells appeared to be lying on the same side of the collector well and had similar slopes with good drawdown response. The t_o intercept for well 8D is 36 min, and the extrapolated t_o for well 10D is approximately 1 min. From field measurements, the $\triangle$0 is 39° and the radii from the pumped well are 300 ft for 8D and 1,250 ft for 10D.

From equation (6)
$$\frac{\sqrt{t_o} \ 10D}{t_o \ 8D} = \frac{\sqrt{1}}{36} \quad 0.166$$

From equation (7)

$$\emptyset \ 10D = tan\text{-}1 \left[\frac{300 \ feet \ x \ \sqrt{1 \ min.} \ x \ Sin \ 39°}{1250 \ feet \ x \ \sqrt{36 \ min.} - 300 \ feet \ 1 \ min. \ cos \ 39} \right]$$

Then 08D = 39° + 1.5° = 40.5°

From equation (2) X1 = 300 ft. sin 40.5 = 194.9 ft

From equation (3) X2 = 1250 sin 1.5 = 32.7 ft

The probable orientation of the fracture on the map results in a N50E trending fracture or extended well. The schist is relatively impermeable and can only allow substantial flows through major discontinuities which are interconnected. Thus the drawdown is more a function of how close the observation well is to the fractures and other discontinuities and not the distance from the pumping well. For example, well 10D, which is 1,250 ft from the pumping well, has a drawdown of 33.2 ft, while well ERT 2, at a 500 ft distance from the pumping well, has a drawdown of only 3.3 ft.

After plotting the zone of increased drawdown (25 ft) as shown on Figure 8, a trough of depression becomes evident. The trough or zone of depression trends approximately N50E from the pumping well. The observation wells with the deepest drawdowns are closer to the fractures and their interconnections.

The observation wells most affected by the drawdown were the deep wells that are 50 to 100 ft into bedrock. The deepest drawdown was seen in two of the deep wells, 10D and 11D, which are located in the source area south of the garage.

Although the flow to the pumping well is linear in the local area, the regional flow is a radial flow. The fracture or collector well is a finite element in an aquifer that can be considered infinite.

PATHWAYS OF MIGRATION

An understanding of the pathways through which the contaminants migrate is based on a knowledge of the groundwater flow regime and the physical characteristics of the contaminated aquifer.

The pathways through which the contaminants are migrating can be assessed. The surficial deposits in the two source areas are thin with moderate permeability. Volatile organic compounds which were dumped either ran off into adjacent streams and swamps or infiltrated rapidly through the overburden into the underlying bedrock.

The bedrock underlying the source area south of the garage is highly fractured and weathered. This allows for good hydraulic communication with the groundwater in the overburden. The bedrock below the suspected source area within the apartment complex is not highly weathered and is less fractured. Contamination is still predominant in the bedrock aquifer at this location. The surficial deposits around both sources have low to moderate levels of volatile organic compounds. The levels of contamination in the bedrock aquifer beneath the sources are high.

The groundwater from the site, including the contaminated zones, discharges to a tributary leading to the Merrimack and the surrounding swamps. The potential flow gradients in the shallow bedrock aquifer would be perpendicular to the equal head contour lines shown on Figure 5. A groundwater divide and a local recharge zone are present in the area east of the garage. The groundwater flow potential in the garage area is to the southeast, whereas the flow potential for the rest of the site is southerly. This holds true on the regional scale, but on the local scale the groundwater flow is controlled by fractures.

The major fracture sets in the area trend N57E and are nearly vertical. Data from the pumping tests show drawdown to be greatest in the source area south of the garage. A trough of depression trends approximately N50E from the supply well to the source area in the vicinity of the garage. The contaminants clearly migrated in a southeast direction from the dumping zones near the garage through the fractured bedrock into the drinking water wells. Further support for this migration pathway is shown by the following: (1) the orientation of the Nashua fault to the south of the site is approximately N50E; this is suspected to be a probable cause of sympathetic fractures within the brittle Oakdale formation of the site area, and (2) the calculations used to estimate a probable fracture orientation using pump test data,[14] suggested a fracture orientation of N50E; this evidence substantiates the pathway of migration from the source area behind the garage to the wells along apartment complex supply well.

CONCLUSIONS

It is clear that migration pathways in the bedrock can be very complex, and an entire study could be devoted to this subject alone. Tracer studies, or vertical seismic profiling, along with extensive pumping tests would help decipher the intricate interconnected flow patterns at this site. This was beyond the scope of this study, which was to establish a hydraulic connection between the contaminated apartment complex supply well and the source of contamination.

The pathways of migration and zone of contamination trend in a northeasterly direction from the apartment complex supply well to the source area behind the garage (Fig. 9). The indicators for this route of migration in the bedrock are the following: (1) fracture trace studies in the nearby area show the majority of fractures to trend N57E, (2) the pumping test data, when plotted, showed a linear drawdown with the greatest drawdown in the source area 1,500 ft away; the linear drawdown and trough of depression is representative of flow in fractured rocks (the trend here was approximately N50E) and (3) the Nashua fault which runs to the south of the study area trends in a northeast direction which would probably produce sympathetic fracturing in the brittle quartz abundant Oakdale formation.

The local flow in bedrock is controlled by the pumping of the apartment complex supply well. During nonpumping conditions, the flow will return to a south and southeast direction similar to the regional flow of the drainage basin.

The following studies should be completed to further assess the complicated hydrogeology of this site:

Key

⊕ FW01 / 0.2 — shallow bedrock well, Field Investigation Team drawdown in feet

◑ FW10D / 33.3 — Deep bedrock well, Field Investigation Team drawdown in feet

◑ ERT01 / 0.8 — Deep bedrock well, Emergency Response Team drawdown in feet

● LGSW / 55.5 — Deep bedrock well, Londonderry Green Supply Well (Pumping Well) drawdown in feet

◑ LGEW / 49.4 — Deep bedrock well, Londonderry Green Emergency Well drawdown in feet

◐ LGAW / 0.0 — Deep bedrock well, Londonderry Green Abandoned Well drawdown in feet

25 — Zone with drawdown greater than or equal to 25 feet

Figure 8
Drawdown During Pumping

Key

⊕ FW09 / 21 — well number
Total Volatile Organic—in ppb as determined by gc/ms
ND—Non Detectable
1—Trace Amount < 2.5

⊕ Monitoring Well— < 50 feet into bedrock

⊕ Monitoring Well—100 to 200 feet into bedrock

Contaminated Areas

Contaminated Source Areas

— Migration pathways for contaminant transport

Figure 9
Contaminant Plume

•The rates and local flow patterns of the contamination must be defined through conducting on-site or falling head permeability tests on all surficial and bedrock units throughout the site.

•Radionuclide tracing or brine slug induction tracing methods should be conducted to provide orientation, spacing and interconnectedness of the fracture sets in bedrock.

•Caliper logging and vertical seismic profiling could be used to provide or check on the above information as well as to indicate the various depths of fractures in the aquifer.

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NDT LOCATION OF CONTAINERS BURIED IN SALINE CONTAMINATED SOILS

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INTRODUCTION

The investigation of sub-surface objects can be approached in two very different ways. The first approach utilizes a destructive test method such as: test pits, excavation trenches, auger holes, core borings and observation wells. While one does indeed "see" the subsurface materials as they are excavated for ease of examination or subsequent testing, such methods are not without drawbacks in identifying and locating buried containers. Some disadvantages of destructive test methods for this purpose are:

- The information obtained is discontinuous over the area investigated
- Permission to enter the properties in question (and excavate therein) may be troublesome or impossible to obtain
- Access for excavation equipment may not be possible at the site in question
- Costs are generally high, e.g., small amounts of excavation can easily be $300/yd^3, and boring costs of $15/ft are not uncommon
- There is a danger to personnel and to the environment due to such materials emptying out of the containers if they have been ruptured or pierced

The second approach used in locating buried containers is the use of a suitable non-destructive testing (NDT) method(s). Within this category are the following methods which have been used, or seem to have general applicability: seismic reflection, seismic refraction, electrical resistivity, electromagnetic (conductivity) induction, induced polarization, eddy current (metal detector), magnetometer, continuous microwave (CW), pulsed radio frequency (ground penetrating radar), infrared radiation and sonar (pulse echo acoustics). All of the above methods are not equally suited for identifying and locating buried containers, but many are, and the interest in these NDT approaches to the problem of subsurface investigation seems to be increasing.

Based on the authors' past work (which will be described later), four of these NDT techniques have direct applicability in the detection and location of buried containers. These techniques are: metal detector (MD), electromagnetic induction (EMI), ground penetrating radar (GPR) and magnetometer (MAG). Each method will be described briefly.

The MD and EMI methods are both inductive methods. A transmitting coil sends a continuous electromagnetic signal to a receiving coil. The signal arrives at the receiver through two major paths. One path is through the air and does not change with the search position. The other path is through the subsurface material and is affected mainly by the local electrical conductivity of the subsurface media. If an anomaly in the subsurface conductivity is encountered, e.g., a buried metal drum, the signal received through

the earth path is changed significantly and the instrument indicates accordingly. These methods are described in more detail in references 1 and 2.

The GPR method operates on exactly the same principle as ordinary aircraft radar. A pulse of electromagnetic radiation is beamed into the ground by a special antenna, and reflections occur from any discontinuity in dielectric constant. The reflected pulse arrives back at the receiving antenna and a display of reflected intensity versus depth is presented on an oscilloscope and on a recorder. This technique is described more fully in Reference 3.

The MAG method measures the local magnetic field (essentially the earth's field) and with it any changes in this magnetic field. The type used in this study is a proton procession model. The local magnetic field is determined by measuring the procession frequency of the proton magnetic moment. This rate is linear in the magnetic field, and as the frequency can be measured very precisely, the magnetic field can also be measured very accurately. A steel drum, being ferromagnetic, changes the local value from the earth's magnetic field and, hence, can be detected. The MAG technique is described in more detail in Reference 4.

PRIOR STUDIES

While each of these methods (and others for that matter) will work under ideal conditions, the typical site where waste material containers are buried is far from ideal. Rather than burial in dry granular soils, drums are usually dumped in swamps, mudflats, water and the like. Furthermore, most of the successful methods the authors have worked with are based on electromagnetic principles, thus soil/water conductivity is a major issue. High conductivity areas, e.g., storage areas, junk yards or ocean water, can severely influence the techniques. To what extent, however, is largely unknown.

With these thoughts in mind, a series of test sites were obtained, containers of various sizes, burial depths, geometric arrangement, etc. were carefully placed, backfilled and then located with the various NDT methods.

The first site was in a nearly ideal dry sandy soil in an open and isolated field.[5] This site provided an excellent starting point and essentially narrowed the authors' thinking from the many NDT methods available to the specific four mentioned previously. Steel containers buried to 10 ft depths were accurately located; they could possibly have been located deeper if stable burial pits could have been excavated. Some plastic containers were also located, but with poorer results. Various container arrays and the boundaries of a "trash dump" were accurately located.

The second site was much more formidable.[6] Here a saturated, silty clay soil overlying shallow shale rock was used. Detection depths were much shallower, approximately 4 ft, and the techniques were troubled by the large amount of background metal in the area (e.g., trailers, equipment, fences, etc.). Results of the four methods were reasonable within these limitations and restrictions.

Recognizing that containers are sometimes dumped directly into water[7] and that the salinity of the water can range from fresh to brine, the third study was directed at these conditions.[8] Containers were placed in water on the bottom soils at four different sites where the salinity of the water ranged from fresh to ocean. To depths of 3 ft of water above the containers, the detection and delineation results were "excellent" to "no good" in direct proportion to the increase in water salinity.

Bearing directly on these three studies is the extent to which groundwater salinity influences the detection capability of these NDT methods. Questions about the dominance of the soil pore water over the solid particular structure, the amount of salt leaching onto the soil particles as one moves back from the ocean front, how far from the ocean front these methods can be used, etc., are all unanswered. This study, the fourth in the series, focuses on the authors' efforts to answer these questions.

DETAILS OF THIS STUDY

The site selected for this study was on an island in a bay at the southern New Jersey shore. Within a distance of approximately 150 ft from the water's edge, the ground surface rose to 10 ft above sea level where it became relatively level in elevation. The soil was a medium to fine, granular, sand indigenous to that area of southern New Jersey. The sand density ranged from loose (near the surface)

to intermediate at a depth of 6 ft, the limit to which we could excavate.

All containers were made of steel and varied in size from 1 to 55 gal. They were placed in hand excavated holes and backfilled to approximately the same density as the adjacent undisturbed soil. The containers were empty and clean.

Four separate test patterns were deployed, each with a specific objective:

•In a low conductivity area, to determine if the results would be similar to study #1 results and if each method was working properly. In this regard, two patterns were used; one employed five 30 gal containers each 25 ft apart at 9, 18, 25, 32 and 50 in. cover respectively; the other used containers with a constant cover of 32 in (also 25 ft apart) but in sizes ranging from 1, 5, 20, 30 to 55 gal respectively.

•In a varying conductivity area extending inland from the ocean front. Here the containers were buried under either 18 or 24 in. of cover (at varying distances apart) and varied in size from 1 to 30 gal.

•In a high conductivity area to attempt to determine the limits of a "trash dump" measuring 9.3 ft × 4.2 ft containing a large amount of miscellaneous metal items (barrels, tables, rods, steel sections, etc.).

Each test pattern was monitored using the four NDT methods described earlier.

RESULTS

The results obtained with the five different sized containers (55, 30, 20, 5 and 1 gal) under a constant soil cover off 32 in . are shown in Figure 2. On the conductivity plot obtained from the EMI

Figure 1
Photographs of Site Conditions at Barnaget Light, New Jersey and the
Four NDT Methods Used: 1a. Electromagnetic Induction; 1b. Metal
Detector; 1c. Ground Penetrating Radar; and 1d. Magnetometer.
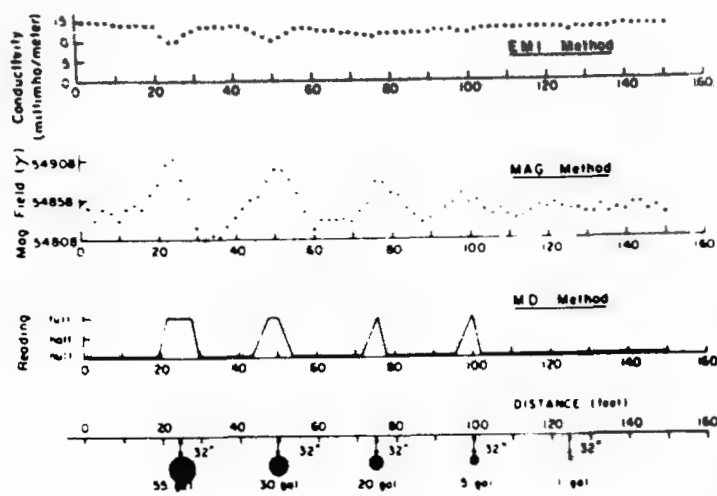
Figure 2
Results of EMI, MAG, MD on Varying Sized Containers Buried
at 32 in. of Cover
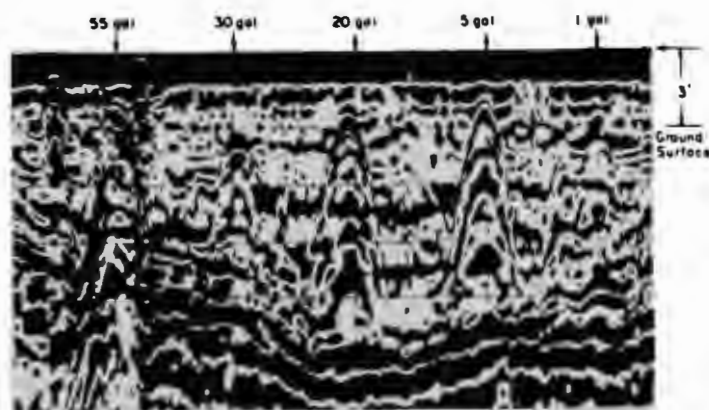
Figure 3
Results of GPR on Varying Sized Containers Buried at 32 in. of Cover

Lastly, the "trash dump" of Figure 7 was monitored. Here the EMI response shows a high background conductivity at the site of 30 to 40 millimho/m, but the heavy metal concentration is easily noted. Also easily noted were the boundaries using the MAG, MD and GPR (not shown) methods. While each of the methods indicated the "trash dump" boundaries, none revealed any detail of items within the "trash dump" itself.
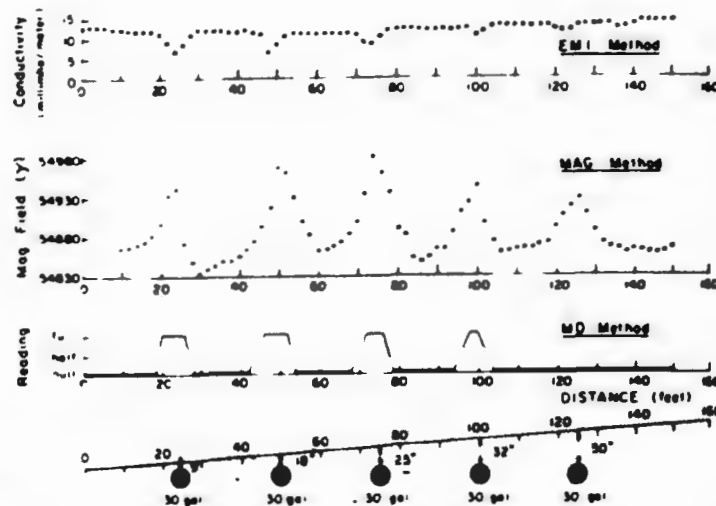
Figure 4
Results of EMI, MAG, MD on 30 gal. Containers Buried at
Depths Varying from 9 in. to 50 in.
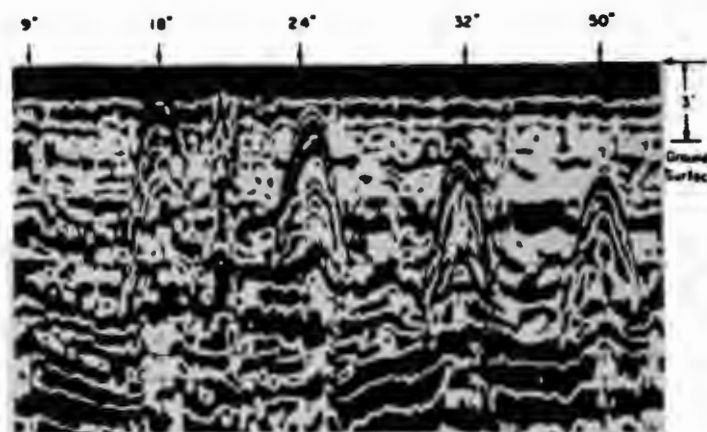
Figure 5
Results of GPR on 30 gal. Containers Buried at Depths Varying
from 9 in. to 50 in.

method, it can be seen that the background area is about 15 millimho/m which is similar to that at study site #1. However, only the two largest size containers can be detected. Plotted beneath this response are the MAG and MD response curves, both of which clearly detected all containers except the 1 gal. The GPR trace of Figure 3 gives a similar response.

The response curves showing the effect of varying soil cover over equal size 30 gal containers are given in Figure 4. Here the EMI and MD methods are seen to be accurate to about 36 in. depth, while the MAG method easily detects all containers, even the one buried at 50 in. depth. The GPR trace of Figure 5 accurately indicates containers buried at all depths.

In Figure 6, a series of six containers (1, 5, 30, 30, 30, 30 gal) were buried at varying distances from the ocean itself. The attempt was to keep all cover depths at 24 in., but the one closest to the ocean constantly flooded out, so 18 in. was used in this case. The EMI plot shows the conductivity exponentially decreasing from 240 millimho/m at the ocean's edge to background conditions 150 ft inland. No containers were located on a plot of this scale; however, the most inland 30 gal containers were detected on a plot with a scale the same as Figures 1 and 2. The MAG response was not defined until the container at 32 ft was encountered. Further inland it performed well. The MD was pinned near the ocean front and it became unpinned only after we were 36 ft inland where it performed well from that point onward. The GPR trace of this scan (not shown) only picked up the 30 gal container at the 149 ft location.

CONCLUSIONS

This study, the fourth in a series, continued the general thrust of burying containers at known locations and depths and then locating them using NDT methods. Thus ground truth was readily and accurately established.

Via the results of the earlier work, it was seen that the metal detector (MD), electromagnetic induction (EMI), ground penetrating radar (GPR) and magnetometer (MAG) were the premier NDT methods to use. Yet, saturated clay soils cause even these methods to be difficult to use and interpret. Most important, the background conductivity levels cannot be too high with respect to the buried anomaly for it to be detected (exception is MAG method). A study of containers under water in gradually increasing saline conditions clearly showed this to be the case.

To extend this finding, the current study was undertaken where an ocean front condition was used as an electrical conductivity ex-

Table 1
General Acceptability of Using Various NDT Methods to Locate Buried Steel Containers in Conditions Listed
(Maximum Penetration Depth in Parentheses)

Soil Type	Percent Saturation	Type of Void Water	Metal Detector	Electromagnetic Induction	Ground Penetrating Radar	Magnetometer
Granular	0 - 20%	fresh	excellent (6 ft)	excellent (10 ft)	excellent (10 ft)	excellent (10 ft)
	10 - 50%	intermediate	excellent (2 ft)	average (4 ft)	excellent (3 ft)	excellent (4 ft +)
	50 - 100%	ocean	no good	no good	poor (2 ft)	-- --
Cohesive	50 - 100%	fresh	excellent (4 ft)	poor (4 ft)	excellent (4 ft +)	poor (4 ft)
Water	100%	fresh	excellent (3 ft +)	excellent (3 ft +)	excellent (3 ft +)	excellent (3 ft^5
	100%	intermediate	poor (3 ft)	no good	no good	excellent (3 ft +)
	100%	ocean	no good	no good	no good	excellent (3 ft +)

treme and conductivity decreased as the survey moved inland. Specifically, it was found that:

- For location of individual buried containers, conductivity greater than 20 millimho/m seriously impairs use of the electromagnetic based systems, i.e., MD, EMI and GPR
- Also adversely affected in this high conductivity area was the MAG performance but for obviously different and unknown reasons
- The boundaries of a "trash dump," however, could not be delineated by any of the methods
- At conductivities less than 20 millimho/m, the four NDT methods performed well and similar to study site #1 which was also in a granular soil but not in an ocean environment

As a generalized conclusion, the authors are now in a position to present a unified view of the use of these four NDT methods to detect buried containers under a wide variety of conditions (Table 1) Here it can be seen that conductivity of the background or of the water in the soil voids or at the site itself presents a formidable obstacle in use of the methods. Each method performed best in fresh water conditions (in water itself or water in the soil voids) and performance gradually decreased as the salinity increased. Therefore, high conductivity is definitely a most limiting factor in buried container detection using NDT methods based on electromagnetic principles.

ACKNOWLEDGEMENTS
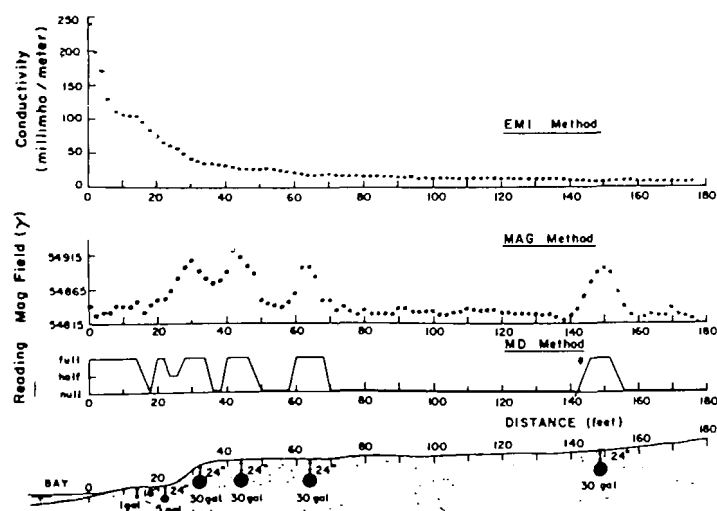
Figure 7
Results of EMI, MAG, MD in Delineating the Boundaries of a "Trash Dump." Scans are Taken Directly Over the Centerline of the "Trash Dump."

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Figure 6
Results of EMI, MAG, MD on Buried Containers as a Function of Varying Conductivity

CONTAMINANTS IN GROUNDWATER: ASSESSMENT OF CONTAINMENT AND RESTORATION OPTIONS

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INTRODUCTION

When contaminants escape from plant sites due to accidental spills, leakage from underground storage or from waste dumps, the potential liability of the site owner is always an issue. If the escaping contaminants enter the groundwater, there is great danger that they will spread and affect the water quality of nearby water-rights holders. Final liability, of course, can only be determined in the courts, when and if the contaminants turn up and the extent of the resulting problem is determined. This determination may be many years in the future because groundwater velocities are generally very slow. However, there is a quick, easy and inexpensive method by which a plant owner can determine: (1) whether a contamination problem exists; (2) when and where it is likely to show up; (3) how serious its effects may be on the water quality of nearby users; and (4) how to control and ultimately correct it.

The owner of a plant that is polluting the air does not have any difficulty to deciding whether or not a problem exists. He can see (or measure) the contaminant leaving his smokestacks. But groundwater is a hidden natural resource and cannot be visually examined except by drilling wells. Hence, one often has no clue as to the existence of a problem. Fortunately, today there is a very powerful tool to take the place of visual examination of the groundwater system under the surface of the earth. Not only does this tool enable one to see what would otherwise be invisible, but it also enables one to compress years or decades into minutes or seconds and predict the future. This very powerful tool is computer modeling.

Defining the Problem

Assessing the potential liability from accidental contamination involves answering two questions. First: Is the contaminant finding its way into the system of underground water? Second: If so, where is it going? To answer the first question, one must determine the rate of contaminant seepage from the spill or leak into the groundwater system. To answer the second question, one needs to determine the velocity and concentration of the contaminant as it migrates in a "plume" through the groundwater system. Models are particularly useful here.

Contaminants generally enter the groundwater system in the "vadose zone," an area above the water table where the soil is not saturated with water. With time, rainfall percolating through the ground leaches the contaminants out of the soil, and they can reach the groundwater. There are two ways to determine if this process is taking place and, if so, in what quantity and at what rate. The first process utilizes the traditional method of drilling portions of the soil and rock and analyzing the drilled cores in a laboratory—a process that can be expensive and time-consuming.

A quicker, more cost-effective method is to make use of existing wells. Pumping several wells takes less time and costs less than drilling cores. While the wells are being pumped and monitored for potential contaminants, they are also removing the contamination from the groundwater (these wells are known as "purge wells"). These wells can also be used later to monitor the progress of cleanup operations, should they be necessary. With projects of this type, the authors have obtained satisfactory agreement between the two approaches: core data and purge well data.

The second option, well pumping, can only be considered if the contaminated water can be treated or diluted to meet discharge standards. If not, a third method, monitoring concentrations in the wells, can be used. Using this information together with groundwater flow, the rate of leaching can be determined.

The study of contaminants in groundwater uses geochemistry and geohydrology. Geochemical properties of concern are the rate of leaching of the contaminants to the groundwater system and the rate at which the contaminants are adsorbed or retained by particles of soil. Geohydrologic properties used to construct a satisfactory model are: the water level and groundwater flow rate; and the porosity, transmissivity and density of the soil or rock.

GEOCHEMISTRY

Computer modelers describe the rate at which contaminants are released into the groundwater as a "source function." The source may be instantaneous, as when all the contamination from an accidental spill reaches a shallow aquifer at the same time. The contaminant may enter the groundwater at a constant rate (for example, from a slow, steady leak in a pond or underground pipe or storage tank).

A third and more complex situation arises when the pollutant enters the unsaturated zone above the water table and is gradually leached out of the soil into the groundwater system through the percolating action of rainfall. The spill may have been instantaneous, but with time less and less of it is getting into the groundwater. This is known as a "decaying source term," because the rate at which the contaminant is entering the groundwater is constantly decreasing. These source functions are described in Appendix A.

Adsorption

A second essential geochemical process is adsorption. Once the contaminant is in the groundwater, one wants to know how fast it will move. To visualize the geochemical process of adsorption, imagine two party-goers walking together down a street toward their

homes at the end. One cannot resist stopping in for a drink at every bar along the way; his progress toward his home is severely retarded. The other—the "non-adsorbing species" in this analogy—walks straight down the street and into his house. Similarly, some contaminants—nitrate, for example—do not adsorb on clays and sand. Ammonia, however, is strongly adsorbed by clay minerals, just as the first party-goer was strongly attracted to drinking establishments.

When groundwater containing an adsorbing species migrates through an aquifer, the species is first removed from solution by adsorption on solids, and then gradually "washed off" as cations in the fresh groundwater displace it from solids back into solution. As a result, a plume of an adsorbing species in groundwater migrates at a much slower rate than the rate at which groundwater moves; an effect called "retardation." The magnitude of the retardation effect, R, is given by

$$R = 1 + \frac{k_d(1-\phi)\rho_g}{\phi} \qquad (1)$$

where ϕ is the porosity, ρ_g is the grain specific density and k_d is the distribution coefficient (a ratio of the contaminant concentration on soil to the contaminant concentration in water at equilibrium).

The magnitude of the retardation effect depends on how strongly the species is adsorbed by the sediment, which in turn is a function of the adsorption properties of sediment and the groundwater composition. In general, aquifer materials having a higher clay content tend to be more adsorbing.

Important adsorption parameters are the distribution coefficient, k_d, and the cation exchange capacity, CEC (the maximum amount of species that can be adsorbed). The parameters can be determined in the laboratory using a core sample taken from the aquifer and natural or synthetic groundwater, or they may be determined in the field using a push-pull test.[1] The field test is preferable as it samples approximately 100 tonnes of sediment compared to a few grams to kilograms in the laboratory.[2]

Conversion of Contaminants

Chemical reactions—e.g., oxidation, reduction, hydrolysys—change, destroy or neutralize contaminants. Sometimes the end product may pose a greater health hazard than the original contaminant. Most organic degradation is carried out by microorganisms. Radioactive materials lose their activity by disintegration. Many of these conversion processes can be modeled using a first-order rate law; i.e., the conversion rate is proportional to the amount present. The model described in Appendix B is capable of handling this type of conversion. Conversion of species is site-specific, and caution should be exercised when applying data from one site to another.

GEOHYDROLOGY

Many tests are available to define the hydrologic characteristics of the groundwater system underlying a site.[3] Details of the various procedures are available elsewhere.[4,5] Hydrologic properties can be estimated from pump test data or computer simulation. Hydrologic properties of interest are the saturated thickness of the aquifer, hydraulic gradient, porosity, hydraulic conductivity and aquifer boundaries. These data can be combined to obtain groundwater velocity.

Dispersion

Dispersion, the mixing of miscible fluids as they flow through granular media, is another geohydrologic phenomenon governing contaminant movement. Dispersion causes the contaminants to contaminate a larger volume, but at lower concentrations. On a microscopic scale, mixing of fluids occurs due to molecular diffusion and microscopic or macroscopic variations in flow velocity. Velocity variations are due to heterogeneities which cause the contaminant front to spread, both laterally and in the major direction of flow. In the aquifer systems of concern, molecular diffusion is negligible compared to the mixing due to velocity variations resulting from heterogeneities.

Dispersive mixing is quantified through the use of the dispersion coefficient, which is known to be proportional to the groundwater velocity;[6] the coefficient of proportionality is known as the dispersivity. Dispersion occuring in the direction of mean flow is termed longitudinal dispersion; dispersion occurring perpendicular to the direction of mean flow is termed transverse dispersion.

Most reported transverse dispersivities are from 20% to 35% of longitudinal dispersivity. Dispersivity obtained using fracture frequency distributions[7] suggests that transverse dispersivity is about 20-40% of longitudinal dispersivity. It is well known that the magnitude of measured dispersivity changes depending on the scale at which the measurements are taken.[8]

Geologic heterogeneities also influence the magnitude of dispersivity. A greater number of heterogeneities combined with an increased travel distance results in larger dispersivity values.[9] Laboratory experiments yield values in the range of 10^{-2} to 1 cm, while dispersivities of 10 to 100 m have been obtained for field problems.[6] The larger the dispersivities, the more the chemical's concentration will tend to decrease; hence, natural restoration will proceed at a faster rate. It is believed that natural aquifer dispersivities increase to a "critical" value, and then remain nearly constant as the dimensions of the aquifer increase. Those dispersivity values obtained from larger-scale history matches of aquifer contamination are felt to be most applicable to pollution problems.

Although dispersivities are important, it may often be impractical to measure actual dispersivities in a reasonable time at the necessary length scale. However, it may be possible to use a push-pull test[1] to determine a local dispersivity which can then be scaled up to the correct length scale using the correlations developed by Lallemand-Barres and Peaudecerf.[10]

THE MODEL

One may choose either a "top-down" or a "bottom-up" approach to designing a computer model.[11] A "top-down" approach begins with a great deal of detail and proceeds through stages of increasing simplification. A "bottom-up" approach, as might be expected, begins with the simplest model and adds details until the point of diminishing returns is reached. That is, additional complexity does not result in any great pay-off in information gained. The bottom-up approach is generally faster and nearly always more cost-effective.

Numerical vs. Analytic Models

Models may be based on numerical techniques (e.g., finite-difference, finite-element and boundary-element methods) or on analytic or approximate analytic solutions. Both methods have their drawbacks: numerical methods suffer from instability and are not practical for the non-specialist; analytic solutions cannot handle complex heterogeneities in porous media. Some numerical models (such as that of Gupta et al.[12]) do not work when dispersivities are less than 80 m.

Frequently, all the data required for a numerical solution are not available, and there may not be time to collect them before the pollution problem becomes serious. In such cases, analytic solutions are more practical. Simple analytic models can also be used to run what is called a parametric or sensitivity study to determine the need for detailed data (determined by the relative sensitivity of the model output to various input data). A sensitivity study is one of the best applications for these models due to their cost-effectiveness.

Whether one chooses a numerical or an analytic model, the underlying idea is what is known as "the conservation of mass." A mass balance equation for a given volume at a particular location may be expressed in words as:

$$\begin{bmatrix} \text{rate of} \\ \text{change of} \\ \text{mass} \end{bmatrix} = \begin{bmatrix} \text{rate of trans-} \\ \text{port of mass} \\ \text{in and out} \end{bmatrix} \pm \begin{bmatrix} \text{rate of trans-} \\ \text{formation} \\ \text{of mass} \end{bmatrix} \pm \begin{bmatrix} \text{sources} \\ \text{of} \\ \text{mass} \end{bmatrix}$$

The rate of mass transport into and out of a location includes transport by convection (flow of water) or by dispersion and diffusion. A simply analytic model is presented in Appendix B.

SENSITIVITY ANALYSIS AND APPLICATION

As noted earlier, a "bottom-up" approach is generally cost-effective, and this is the approach the authors recommend. The authors also recommend the use of analytical and quasi-analytical models wherever possible. Such models are particularly suited for a number of runs required for sensitivity analysis. Ammonia and nitrate migration are used here as an example; other contaminants can be handled in similar fashion.

As an example, consider the site shown in Figure 1. It includes a plant, underground storage tanks and above-ground packing and materials handling area. Over the years, ammonia and nitrate have been spilled. Both have leached from the soil and now appear in the groundwater system, while 200,000 kg of ammonia are still in the ground. (It is assumed that sufficient preventive measures have been taken so that further ammonia and nitrate are not being spilled.) Management is now faced with the question of whether or not a pollution problem exists. If the answer is yes, then what is the most cost-effective remedy? The sensitivity analysis can provide a quick answer to these questions.

For this example, the authors assume that groundwater velocity is 60 m/yr, the aquifer is 15 m thick and porosity is 30% with a grain density of 2.6. As the groundwater velocity increases, the dispersion coefficient, which is the product of the aquifer's dispersivity and groundwater velocity, will increase. However, the time of arrival of maximum concentration at a fixed point will decrease, allowing less time for the plume to disperse (although the plume is dispersing at a higher rate). The result of these competing effects is that maximum concentration will be the same. By manipulating the equations given in Appendix B, one can rigorously prove that groundwater velocity does not significantly influence maximum concentrations away from the site, but it does govern the plume's arrival time at any point. Increasing dispersivity, on the other hand, will lower the concentration when the peak arrives at the same selected point regardless of the groundwater velocity. A longitudinal dispersivity of 35 m and a transverse dispersivity of 12 m are selected. Dispersivities are scale-dependent. Small-scale dispersivities can be easily measured (for example, by using a push-pull test[1]), but larger-scale dispersivities are normally estimated due to time and budget constraints. Therefore, the dispersivity was not varied in this example, although it can be easily varied in the model.

If the groundwater is saturated with oxygen, and 100% of the oxygen is used to convert ammonia to nitrate, only 2 mg/l of nitrate as N would be present. A 100% conversion efficiency is unlikely. Freshwater intrusion and infiltration, and diffusive transport of oxygen through the vadose zone to the groundwater, are possible mechanisms which will help convert ammonia to nitrate. The oxygenated near-surface groundwater would then have to mix vertically in the aquifer to convert ammonia to nitrate. The authors do not
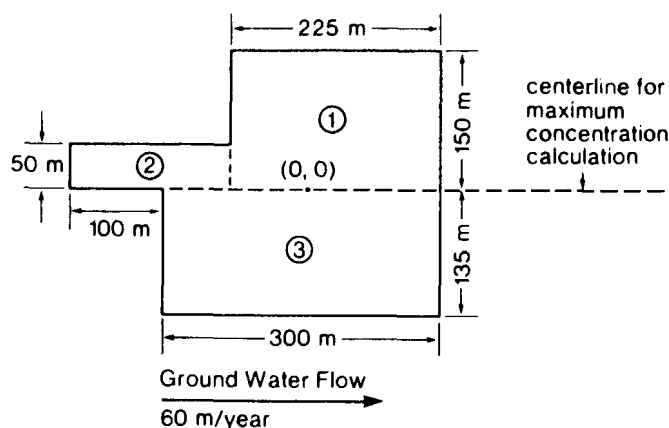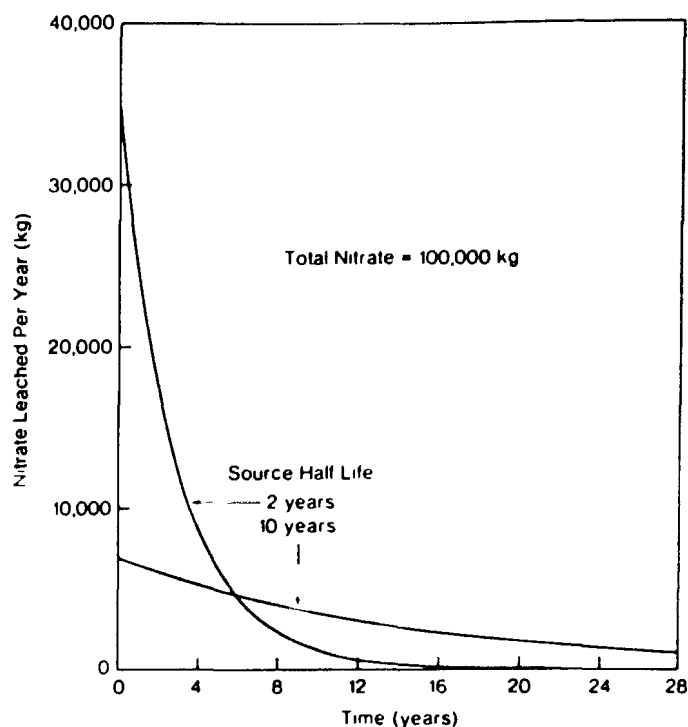
Figure 2
Amount of Nitrate Leached per Year into the Groundwater System

know of any documented case of this phenomenon and expect continuous conversion of ammonia to nitrate in groundwater to be insignificant. However, the model described in Appendix B is capable of handling the conversion of one species to another.

Nitrate

Nitrate does not adsorb on soil, and therefore its progress is not retarded. The authors past experience indicates that more nitrate will enter the system in the early stages, and as time passes less and less will enter the system. The dispersion of nitrate will be modeled as a first-order rate law decaying source strength. Generally the authors' experience has been that half-lives for leaching of this type of contaminant are greater than 3 years and less than 10 years; however, the rate could vary widely. Using a 2-year half-life ($t_{1/2}$ = 2), 2 years will be required for half of the nitrate (50,000 kg) to appear in the groundwater system, and then every 2 years the nitrate leaked into the system will decrease by half of its previous amount (Fig. 2). For example, with a 2-year half-life, one-fourth of the nitrate will remain in the ground above the water table and three-fourths will have leached into the aquifer after 4 years, depending on soil type and rainfall. The two values selected, 2 years and 10 years, tend to bracket the range.

The maximum nitrate concentration is shown as a function of distance in Figure 3. Also shown is the time required for maximum concentrations to occur. For both the source half-lives considered, the highest concentration that will ever be seen occurs just inside the site boundary. For a source half-life of 2 years, this value is 35 mg/l as N, and it is seen after 4 years. For a source half-life of 10 years, it is 13.6 mg/l as N and occurs in 7 years.

When nitrate is added slowly to the groundwater, as with a 10-year half-life, a lower concentration may be expected at any given time and place than when greater amounts are added at early stages, as with a 2-year half-life. Similarly, when the contaminant is added slowly, it also takes longer for high concentrations of nitrate to appear. For example, it takes 25 years for a maximum concentration of 11 mg/l as N to appear at 14000 m when $t_{1/2}$ = 2 years compared to 30 years for a maximum concentration of 6 mg/l as N to appear at the same location for $t_{1/2}$ = 10 years (Fig. 3). Concentration data from monitor or purge wells can be used to determine $t_{1/2}$.

Figure 1
Site Layout for Model Calculations
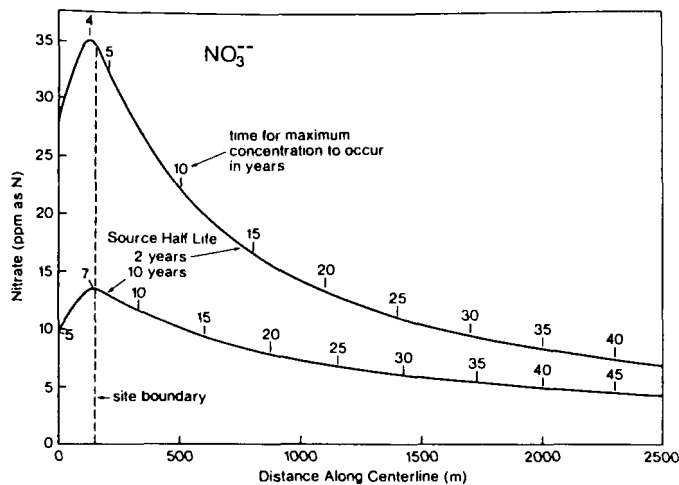
Figure 3
Maximum Nitrate Concentration as a Function of Distance
and Nitrate Leach Rate (half-life)

Table 1
Amount of Nitrate in Various Regions for Nonuniform
Distribution in Figure 6

Region in Figure 1	Nitrate in place (kg)	Concentration relative to region 1
1	40,663	1
2	31,627	3
3	27,710	0.56
Total: 100,000		

Figure 4
Nitrate Concentration (ppm as N) Contours after 25 Years
(t½ = 10 years)

Figure 5
Nitrate Concentrations at Selected Locations vs. Time for
t½ = 2 years.

The configuration of a plume after 25 years for a source half-life of 10 years is shown in Figure 4. Nitrate still appears at the site, and the plume widens as distance from the site increases due to dispersion. Dispersion dilutes concentrations and tends to keep maximum concentration at a low level as distance from the site increases (see Fig. 3).

The concentrations occurring at various points along the plume centerline are shown in Figure 5. It takes some time before nitrate is seen down-gradient. Once it arrives at a location, its concentration slowly increases to a maximum and then begins to decrease. As the distance increases, maximum concentration decreases, and it also takes longer for the plume to disappear.

In Figures 3, 4 and 5, the authors assumed that nitrate leached into the groundwater system uniformly over the site. However, this is rarely the case. Some areas are generally more contaminated than others. Should one spend a fortune to define relative rates of contamination within the site? Figure 6 shows that the answer is no if one is concerned with liabilities at some distance from the site. If the nitrate concentration near the site is important, then one might consider defining the source term more accurately. The relative amounts of nitrate in various regions in Figure 1 and the relative concentrations with respect to region 1 were used to define nonuniform distribution of nitrate (Table 1). For example, one initially might see 21 mg/l nitrate as N in region 1, 63 mg/l in region 2 and 12 mg/l in region 3. Even in cases where the initial concentration is much higher, the knowledge of its distribution is not important if the bulk rate of leaching into groundwater is available or can be estimated from purge or monitor well data—the exception again being if the point of concern is near the site.

Remedial Actions

Drinking water standards for nitrate have been established at 10 mg/l as N.[13] If the source half-life is 2 years, then potential liability exists within 1500 m down-gradient of the site boundary (Fig. 3). Various courses of action may be considered by management at this point. Three of these are described below.

Natural Restoration

The natural mechanisms of groundwater flow and dispersion will eventually lower concentrations to acceptable limits. In many cases, concentrations will be higher near the site early; thus, some downstream water users may be adversely affected, requiring mitigation or relocation of water sources. However, this impact can be reduced or eliminated by pumping with purge wells until natural restoration occurs. The financial consequences of this option will vary widely from one situation to another.

Figure 6
Downstream Concentrations for Uniform and Nonuniform Distribution
of 100,000 kg of Nitrate Leaching into Groundwater with
t½ = 2 Years

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Purge Well

Install a purge well at an optimum location on the site, using a computer model to ensure the maximum containment of nitrate within the site. Treat or dilute the water before discharging. A pump with a capacity of 1.1 m³/min is required if it is located at the center of the site, as in this example. The costs of drilling a 30 m well can vary widely; here, the cost is estimated at $10,000. If the pump operates at 60% efficiency and lifts water to a total dynamic head of 60 m, it will cost $8,000 a year to keep the pump running, assuming that electricity costs 5¢ 1 kwh.

Pumping will have to continue for nearly 5 years to reduce concentrations below the drinking water standard (Fig. 7). The total cost, then, would be about $50,000, excluding the cost of water treatment or dilution and labor and analytical costs (additional costs will depend on the specific problem). In this case, installation of a purge well, followed by natural restoration, may in fact be the next best remedial action available.

Slurry Trench or Wall

A slurry trench constructed around the site to contain the nitrate would need to be at least 20,550 m². Slurry trench costs vary from $40 to $250/m² at medium depth.[14] Assuming a cost of $100/m² of trench area, the cost would be at least $2,000,000. If only a slurry wall downgradient is used to control the nitrate escape from the site, the cost would be about $750,000. In addition, monitor wells will be required to detect any potential leaks. These costs are only 60-80% of the total costs to be incurred to complete the slurry wall or trench.

Other pumping schemes are available. For example, if water is pumped upgradient of the site so that the hydraulic gradient is reversed near the site, the nitrate would not move out of the site, or would do so very slowly. This course of action may conflict with the rights of other groundwater users and, of course, it would not restore the site. Other options may include artificial recharge or some combination of these choices.

Ammonia

The authors have assumed that ammonia will leach to groundwater with a source half-life similar to that of nitrate. Ammonia leach rates for half-lives of 2 and 10 years are shown in Figure 8. Ammonia leach rates are twice as large as those for nitrate since the initial amount in the ground is twice as much (200,000 kg of am-

Figure 8
Amount of Ammonia Leached per Year into Groundwater System

monia compared to 100,000 kg of nitrate). The maximum concentrations is plotted as a function of distance in Figure 9; also shown is the time at which maximum concentrations will occur. Note that ammonia (Fig. 9) travels much more slowly than nitrate (Fig. 3). This difference occurs because ammonia is adsorbed and therefore retarded, while nitrate does not adsorb. A value of one was used for the distribution coefficient in Figure 9. When travel times are large compared to source half-lives, maximum concentrations are independent of source half-life more than 1500 m (about a mile) from the site. The effect of dilution due to infiltration has not been included in this analysis.

The effect of the distribution coefficient (k_d) on ammonia concentrations 1000 m from the center of the site is shown in Figure 10. As k_d increases, maximum concentration decreases. The higher the distribution coefficient, the more ammonia is adsorbed on the soil; thus, less ammonia will appear in the groundwater. A high distribution coefficient also results in high retardation; travel time is increased, allowing for greater dispersion and, hence, a wider plume. Concentrations are very sensitive to the value of k_d used (Fig. 10). The distribution coefficient is, therefore, a very important parameter in studying the spread of a contaminant.

Figure 7
Distance from Site Boundary Beyond Which Nitrate Will Not Exceed 10 ppm at N vs. Purge Well Pumping Time
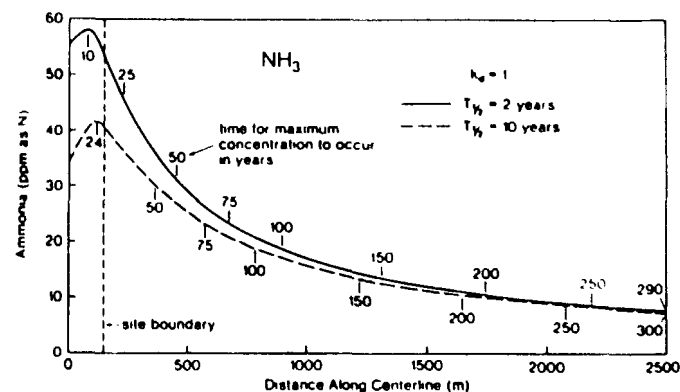
Figure 9
Maximum Ammonia Concentrations as a Function of Distance and Ammonia Leach Rated (half-life)
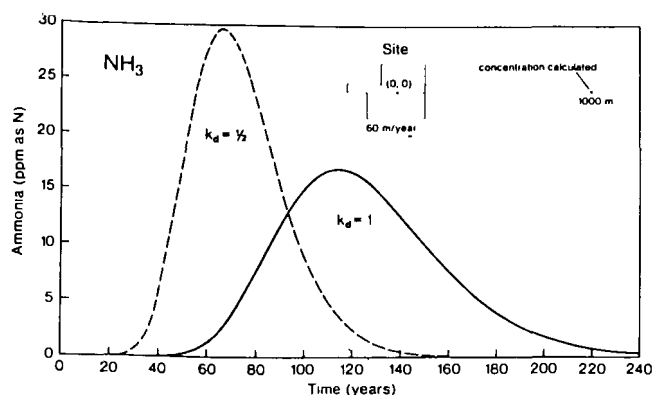
Figure 10
Effect of Distribution Coefficient (k_d) on Ammonia Concentrations at 1000 m from Center of Site ($t_{1/2}$ = 2 years)
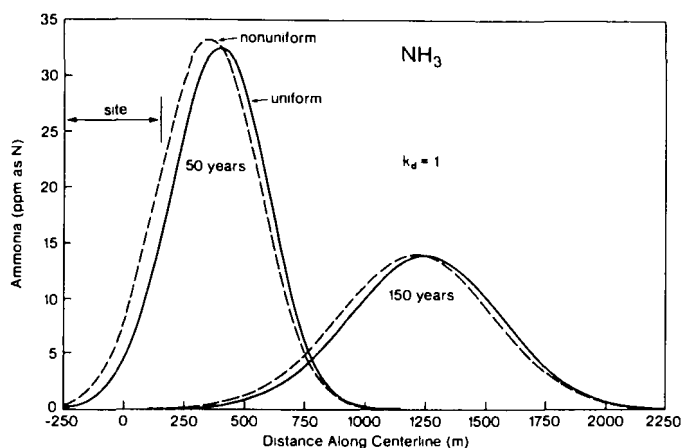
Figure 11
Downstream Concentrations for Uniform and Nonuniform Distribution of 200,000 kg of Ammonia Leaching into Groundwater with $t_{1/2}$ = 2 years and k_d = 1
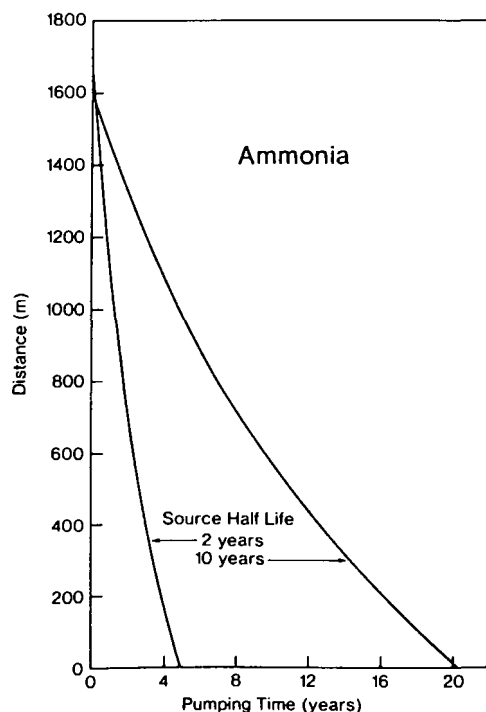
Figure 12
Distance from Site Boundary Beyond which Ammonia Will Not Exceed 10 ppm as N vs. Purge Well Pumping Time

The effect of nonuniform distribution of ammonia over the site is shown in Figure 11. Again, concentrations very near the site are dependent on the ammonia distribution within the site, while concentrations away from the site are not sensitive to the relative distribution of ammonia. The amount of ammonia from each region in Figure 1 and the relative concentrations used for nonuniform distribution in Figure 11 are given in Table 2. (Figures 9 and 10 are for uniform distribution of ammonia over the site.)

Table 2
Amount of Ammonia in Various Regions for Nonuniform Distribution in Figure 11

Region in Figure 1	Amount of Ammonia (kg)	Concentration relative to region 1
1	81,325	1
2	63,253	3
3	55,422	0.57
Total: 200,000		

Remedial Actions

No drinking water standards have been established for ammonia. However, a standard of 0.02 mg/l as un-ionized ammonia for freshwater aquatic life has been established.[13] For a temperature of 15 °C and a pH of 6.5, the concentration can be as high as 19 mg/l as N. For a pH of 7.5, this value is reduced to 2 mg/l. Hence, if the groundwater flows to a nearby stream or river, these pH- and temperature-dependent ammonia standards must be considered together with the natural dilution provided by the stream.

In this example, using the maximum allowable concentration of 10 mg/l as N (based on the aquatic life standard), Figure 9 indicates that a problem may exist for any down-gradient users within 1600 m of the site. Again, three options can be considered:

Natural Restoration

Take no remedial action, and relocate down-gradient users or face possible liability. The financial consequences of this option will vary greatly depending on the situation. As with nitrate, a combination of purge wells followed by natural restoration may be the most viable option.

Purge Well

Install a purge well to contain all the ammonia within the site, product ammonia with water and dilute or treat the water before discharging it. Depending on the source half-life (2-10 years), the purge well will need to be in operation for 5-20 years (Fig. 12), producing about 1.1 m³/min at a cost of $8,000 a year. Thus, the total cost could be $50,000-$170,000 in addition to dilution or water treatment costs. This option still looks favorable compared to the slurry trench.

Slurry Trench

As discussed for nitrate, constructing a slurry trench to contain ammonia within the sited will cost millions of dollars.

The model can also be used to evaluate other remedial actions.

CONCLUSIONS

A site owner confronted with a contamination problem has a number of alternative remedial measures of varying cost and effectiveness to mitigate his problem. These include, in the most probable order of increasing expense:

- Natural restoration
- Pumping up-gradient to stabilize the contaminated water
- Purge well systems to contain and remove contaminated water; the water is either diluted or treated and discharged on the surface
- Complete and partial slurry trenches with clay capping
- Active restoration including chemical flushing

The cost of these options will depend on the site. If the contamination is very localized, slurry trenches can be the most cost-effective method. However, if the material at the base of the slurry trench is not continuous and of sufficiently low permeability, then contamination will still leak to the groundwater system, and the first three options must be given serious consideration. The authors primarily address the natural restoration option with the purge well method. This purging might reduce contamination under the site sufficiently to let natural restoration take over.

If only natural restoration is employed, the drinking water standard for nitrate will be exceeded downstream from the site. However, for both assumed leaching rates this can be avoided by using a purge-well system for 4-5 years. As shown in Figure 7, pumping can be stopped after 5 years, and natural restoration will be adequate to prevent serious contamination in the future and to effect site restoration.

Ammonia requires more careful consideration: first, because there is generally more of the species in a fertilizer plant, and second, because it is a retarded species which allows concentrations to build up under the site. Nitrate takes 4-7 years for the peak concentration to move from under the site. Ammonia, on the other hand, takes 15-25 years, owing to retardation on clays. Since it remains under the site so long, leachate arriving in the aquifer continues to increase in concentration until the plume moves off-site.

For a 2-year source half-life, approximately 4 years of purge well pumping are sufficient to make the transition to natural restoration. The 10-year half-life requires careful consideration of the impact on nearby streams and water supplies. If 10 mg/l (as N) is an acceptable concentration, then the point of impact must be slightly greater than 1 km from the site to avoid contamination and still allow shutting down the purge well system.

Other scenarios can be considered, especially if the data show considerable uncertainty. The computer modeling approach is virtually the only method available to estimate the impact of contaminants and assess the potential liability and effectiveness of remedial measures.

ACKNOWLEDGEMENTS

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APPENDIX A:
Source Functions

Instantaneous Source

When M_0 mass of the contaminant reaches groundwater instantaneously over an area A, the source function, C_s, is given by

$$\dot{C}_s(t) = \frac{M_0}{\phi AbR} \delta(t) \tag{A-1}$$

where ϕ is porosity, b is the saturated thickness, R is the retardation factor defined by eq. 1, and $\delta(t)$ is the delta function, which is zero except at $t = 0$, when it is equal to unity.

Constant Rate of Contamination

The source function for a constant rate of contamination between time t_1 and time t_2 is given by

$$\dot{C}_s(t) = \frac{M_0}{\phi AbR(t_2-t_1)} \quad \text{for } t_1 < t < t_2 \tag{A-2}$$

$$0 \qquad \text{otherwise}$$

where $\dot{C}_s(t)$ is the rate of contamination given on concentration and M_0 is the total amount of contaminant to appear in the groundwater at constant rate between time t_1 and time t_2.

Exponentially Declining Contamination Rate

It is assumed here that the rate of leaching of contaminant (M) is proportional to the total amount (M) present at the time, i.e.,

$$\dot{M} = kM. \tag{A-3}$$

When eq. A-3 is integrated, one obtains

$$M = M_0 e^{-k(t-t_0)}, \tag{A-4}$$

where M_0 is the total mass present in the ground at time t_0.

The numerical value of k as well as M_0 (total amount in the ground) can be estimated either by fitting various sets of production data over time to eqs. A-3 and A-4, or by comparing production in a particular year to the measured amount in the ground at that time. It is assumed that all the con-

taminants released to the aquifer were produced, say, by the purge well, and did not escape the contaminated area. The authors recommend use of the relative least-squares method to fit the data because it has the advantage of attempting to optimize the fit to maintain the same average percentage error over the range of data. This makes the fit better at lower production values than the standard least-squares approach, which minimizes absolute error. Thus the predicted values beyond the range of data should be somewhat better.

The k value is related to the half-life ($t_{1/2}$) of the source by the equation

$$t_{1/2} = \frac{0.693}{k} .$$ (A-5)

The source half-life is the time required to reduce the amount of contaminant in the ground by half, or equivalently, the time required to reduce the total amount of contaminant released to half the original. A typical production curve from a purge well is shown in Figure 2.

The source function in terms of concentration may be written as

$$\dot{C}_s(t) = \frac{kM_0}{\phi AbR} e^{-k(t-t_0)} .$$ (A-6)

APPENDIX B:
The Computer Model

The basic equation for the transport of a solute in saturated porous media can be written as:

$$\frac{\partial c}{\partial t} = \langle V_i \rangle \frac{\partial c}{\partial x_i} + D_{ij} \frac{\partial^2 c}{\partial x_i \partial x_j} - R_x$$ (B-1)

where

c	= concentration [M/l^3]
t	= time [T]
V_i	= mean value of ith component of fluid velocity [L/T]
x_i, x_j	= space coordinates [L]
D_{ij}	= i,j component of hydrodynamic dispersion tensor [L^2/T]
R_x	= rate of conversion or adsorption of solute

The general solution was derived by G. de Josselin de Jong[15] using probability theory. Effects of adsorption are accounted for by introducing a retardation factor, R,[16,7] as defined by eq. 1. The retardation factor concept is valid for dilute concentrations.[17]

The specific solution for instantaneous contamination from a rectangular site (x_0 by y_0) centered at the origin was given by Way and McKee.[6]

$$C(x,y,t) = \frac{C_0}{4} \left[\text{erf} \left(\frac{x+x_0/2 - V_x t/R}{\sqrt{4D_L t/R}} \right) - \text{erf} \left(\frac{x-x_0/2 - V_x t/R}{\sqrt{4D_L t/R}} \right) \right]$$
$$\cdot \left[\text{erf} \left(\frac{y+y_0/2 - V_y t/R}{\sqrt{4D_T t/R}} \right) - \text{erf} \left(\frac{y-y_0/2 - V_y t/R}{\sqrt{4D_T t/R}} \right) \right] .$$ (B-2)

Eq. B-2 is valid for a uniform groundwater velocity field. V_x and V_y are the groundwater velocity components in the x and y directions, and D_L and D_T are longitudinal and transverse dispersion coefficients. The sides of the rectangle are parallel to the x-axis or y-axis, and the x-axis coincides with the direction of longitudinal dispersivity.

For a constant strength contamination source, for a time period of T from a rectangular site (x_0 by y_0) centered at the origin, the concentration of solute at any time, t, and space is given by

$$C(x,y,t) = \frac{C_0}{4} \int_0^{T'} \left[\text{erf} \left(\frac{x+x_0/2 - V_x(t-\tau)/R}{\sqrt{4D_L(t-\tau)/R}} \right) - \text{erf} \left(\frac{x-x_0/2 - V_x(t-\tau)/R}{\sqrt{4D_L(t-\tau)/R}} \right) \right]$$
$$\cdot \left[\text{erf} \left(\frac{y+y_0/2 - V_y(t-\tau)/R}{\sqrt{4D_T(t-\tau)/R}} \right) - \text{erf} \left(\frac{y-y_0/2 - V_y(t-\tau)/R}{\sqrt{4D_T(t-\tau)/R}} \right) \right] d\tau ,$$ (B-3)

where

$$T^1 = \text{Min} \left\{ t, T \right\} .$$ (B-4)

For an exponentially decaying strength of contamination, the concentration of solute at any time, t, and space is given by

$$C(x,y,t) = \frac{C_0}{4} \int_0^t \exp \left(-0.693 \, \tau/t_{1/2} \right)$$
$$\cdot \left[\text{erf} \left(\frac{x+x_0/2 - V_x(t-\tau)/R}{\sqrt{4D_L(t-\tau)/R}} \right) - \text{erf} \left(\frac{x-x_0/2 - V_x(t-\tau)/R}{\sqrt{4D_L(t-\tau)/R}} \right) \right]$$
$$\cdot \left[\text{erf} \left(\frac{y+y_0/2 - V_y(t-\tau)/R}{\sqrt{4D_T(t-\tau)/R}} \right) - \text{erf} \left(\frac{y-y_0/2 - V_y(t-\tau)/R}{\sqrt{4D_T(t-\tau)/R}} \right) \right] d\tau ,$$ (B-5)

where source strength decays according to

$$C_s = C_0 e^{-0.693t/t_{1/2}} ,$$ (B-6)

i.e., every $t_{1/2}$ years source strength reduces to half of the original. Integration in eqs. B-3 and B-5 is carried out numerically in the computer model. Other types of source functions can be handled similarly. If more than one rectangular site is of concern, then concentrations resulting from each site are added, to obtain the final concentration at a point. A mass balance of 99.99% was observed for test problems, giving us confidence in the numerical integration, mathematical formulation, and the computer model. First-order conversion of one species to another is easily handled by introducing a factor similar to "exp ($-0.693 \, t/t^c_{1/2}$)" in eqs. B-2, B-4, and B-5, where $t^c_{1/2}$ is the half-life for conversion of the contaminant; the superscript "c" distinguishes it from the source half-life, $t_{1/2}$.

CONTROL TECHNOLOGY USED IN AN AQUIFER CONTAMINATION CRISIS SITUATION

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INTRODUCTION

The Verona Well Field provides potable water to 35,000 of the residents of the City of Battle Creek, MI, part of the water supply requirements for two major food processing industries, the total water supply requirements for another food processing industry and a variety of other commercial and industrial establishments.

During August, 1981, while conducting routine testing of private water supplies, the Calhoun County Health Department discovered that the water supply from the Verona Well Field was slightly contaminated with Volatile Organic Compounds (VOCs). Followup testing by the Calhoun County Health Department and the Michigan Department of Public Health (MDPH) revealed that ten of the city's 30 wells contained detectable levels of VOCs. The MDPH then began weekly sampling of the well field. During that same period, the MDPH began sampling private residential wells in the area to the south of the well field.

Approximately 80 private wells were found with varying concentrations of contaminants. Several of the private wells had VOC contamination levels up to 1,000 μg/l, with one well having a dichloroethylene concentration of 3,900 μg/l. A bottled water program was implemented for the area residents during the time a water supply system was being constructed to provide city water to the affected area. The system is now complete and the bottled water program has been discontinued.

Problem Analysis

During the course of hydrogeologic investigations to identify and characterize the sources and extent of contamination, the MDPH continued sampling wells within the Verona Well Field. In the period between September, 1982 and January, 1984, the water quality of many wells deteriorated and additional wells were affected. Through January, 1984, blending water from the least affected wells with higher concentration wells kept distribution system water below the 10^{-6} cancer risk level. Projections for increased pumping and potentially increased concentrations in the summer of 1984 indicated that blending water within the well field could not reduce the risks below the 10^{-5} cancer risk level.

To avoid the potential for reaching unacceptable levels in the drinking water supply, an Initial Remedial Measure (IRM) was studied through a Focused Feasibility Study[1] and was implemented before the increased summer pumpage caused further deterioration of water quality.

Seven compounds at various concentrations have been identified repeatedly in the well field. These are listed in Table 1 with the ancillary detected compounds and available health criteria.

SITE DESCRIPTION

The Verona Well Field is located in the northeast corner of the City of Battle Creek. The well field consists of three wells west of the river in Bailey Park and 27 wells and a major pumping and water treatment station east of the Battle Creek River. The three wells developed west of the river are connected to the Verona Well Field by a pipeline under the river. Land use in the vicinity of the Verona Well Field is light to heavy industrial with a residential area to the south and the Grand Trunk Western Railroad marshalling yard directly east of the field.

The monthly Average Daily Demand (ADD) for water produced at the Verona Well Field was between 9.7 mgd and 1; mgd for the last 2 years. The Maximum Daily Demand (MDD) during the prev-

Table 1
Contaminant Characteristics

Contaminant	Higest Observed Concentration (ug/l)	Long-Term Health Advisory (ug/l)	Cancer Risk Level 10^{-6} (ug/l)
Frequently Detected			
1,1 Dichloroethane (1,1 DCA)	34	-	-
1,2, Dichloroethane (1,2 DCA)	8	-	0.6
1,1,1 Trichlorethane (1,1,1 TCA)	150	1,000	22
cis-1,2 Dichloroethylene (cis 1,2, DCE)	229		
1,1 Dichloroethylene (1,1 DCE)	11	-	0.034
Trichloroethylene (TCE)	62	75	2.8
Perchloroethylene (PCE)	94	20	0.9
Sporadically Detected			
Methylene Chloride*	5.5	150	0.19
1,2 Dibromoethane*	3	-	0.055**
Chloroform*	15	-	0.19
Benzene*	9	70	0.67
Ethylbenzene*	5	-	-
Toluene*	57	100**	
Xylene*	26	-	
1,2 Dichlorobutane*	detected	-	-
Vinyl Chloride*	1	-	1.0**
trans-1,2-dichloroethylene*	detected	-	

* Sporadic, generally nonrecurring contaminants observed in some Verona wells.

** These levels were established by the National Academy of Sciences. All others were taken from the USEPA and the Cancer Assessment Group.

ious two years, 1982 and 1983, was at 18.8 mgd. As expected, the historical demand increased through the months of May, June and July with the MDD of 18.8 mgd occurring in July of 1983. The ADD in 1983 was similar to that in 1982; however, a comparison of MDD for both years indicates much higher maximum daily usage in 1983 than in 1982.

Hydrogeology

The Verona Well Field is located adjacent to the Battle Creek River in an area mapped as glacial alluvial deposits.[2] These deposits vary in thickness from 8 to 77 ft in the vicinity of the well field. The alluvial depolsits are in direct connection with the Battle Creek River. The well field causes a substantial amount of induced infiltration from the river. The area outside the alluvial valley is underlain by glacial outwash deposits.[2] Underlying the glacial deposits is the Marshall sandstone formation. The sandstone is a fine to medium well cemented sandstone and varies from approximately 70 to 130 ft in thickness in the vicinity of the Well Field. The base of the sandstone grades into the Cold Water Shale which is the lower boundary of the aquifer tapped by the Verona Well Field. Each well of the well field is cased through the glacial deposits (18 to 77 ft) into the Marshall Sandstone, with an open hole in the rock. The depth of casing into the rock varies but is generally about 10 ft. Water transmission through the Marshall formation appears to occur primarily through fractures in the sandstone. The overall hydraulic conductivity of the aquifer is estimated to be approximately 1×10^{-1} cm/sec.

PUMPING AND CONTAMINANT HISTORY

The contaminants at the Verona Well Field were first identified in the southern and eastern wells in September, 1981. Pumping at this time was centered in the southern wells. Figure 1 is a water table map based on wells installed by the USEPA Technical Assistance Team (TAT) and United States Geological Survey (USGS) the year after the contamination was identified. This map indicates that the cone of depression was centered in the southern and central portion of the well field.

The extent of contaminant spread shortly after discovery of the contamination (January through April, 1982) is shown in Figure 2. The total VOCs shown on this drawing represent the sums of the volatile organic compounds identified in each well. Three zones of contamination are shown: a zone with 1 to 50 µg/l total VOCs, a zone with total VOCs in the range from 50-100 µg/l and a zone showing concentrations greater than 100 µg/l. Inspection of Figure 2 shows the contaminants were confined to the southern and eastern portions of the well field in early 1982.

As the southern and eastern wells became more contaminated, pumping was shifted to clean wells further north in the field. The cone of depression from pumping measured in all available monitoring wells on Feb. 1, 1984 is illustrated in Figure 3. Comparison of Figure 1 with Figure 3 illustrates the shift in pumping from the south to the north between August, 1982 and February, 1984.

Concurrent with the shift in pumping to the north, the contaminants also migrated to the north. The extent of contamination in January, 1984 is shown in Figure 4. Comparison of this map with Figure 2 illustrates the contaminant migration further north into the well field. Closer inspection of the VOC levels in each well on Figures 2 and 4 indicates that contamination at several wells had increased two- to three-fold during the 2-year period. For example, concentration of VOCs in well V35 had increased from 173 ug/l to 343 µg/l total VOC. Wells in the interior and northern portion of the well field that previously had levels below detection limits now had levels ranging from 2 ug/l (well V37) to 45 µg/l total VOC (well V38).

ENDANGERMENT ASSESSMENT

As mentioned previously, the City has been able to provide water of acceptable quality by blending contaminated well water with primarily uncontaminated water. However, as the contaminant plume

NOTES:

1. WATER LEVELS OBTAINED FROM USGS.
2. RIVER STAGE AT THE DAM IS APPROXIMATELY 823.9 ABOVE DAM AND 818 BELOW DAM.
3. WATER LEVELS AVAILABLE ARE NOTED ADJACENT TO WELL.
4. WATER TABLE CONTOURS ARE DASHED WHERE INFERRED.
5. WELL LOCATIONS ARE APPROXIMATE, AND WATER TABLE MAP IS FOR PRELIMINARY USE ONLY.
6. BASE MAP ADOPTED FROM USGS PLANIMETRIC MAP.

[EXPLANATION]
- ●E7 LOCATION AND NUMBER OF WELL INSTALLED BY U.S. GEOLOGICAL SURVEY
- ●T5 LOCATION AND NUMBER OF WELL INSTALLED BY ECOLOGY AND ENVIRONMENT, INC. TECHNICAL ASSISTANCE TEAM (TAT)
- ●V6 / YT2 / VO1 LOCATION AND NUMBER OF PRODUCTION WELL, TEST WELL, AND OBSERVATION WELL INSTALLED AND OWNED BY THE CITY OF BATTLE CREEK
- ●M OBSERVATION WELL OF STATE OF MICHIGAN PROPERTY
- ▲ STREAM GAGING STATION, CONTINUOUS
- △ STREAM MEASURING SITE, MISCELLANEOUS
- ▨ LOCATION OF THOMAS SOLVENTS FACILITIES
- ⬥V8 APPROXIMATE WELL LOCATION, LETTERS INDICATE APPROX. DEPTH OF WELL COMPLETION, S-IN THE SAND AND GRAVEL (40 FT.), I-IN THE UPPER BEDROCK (70 FT.), D-IN THE LOWER BEDROCK (140 FT.)
- ⬥W APPROXIMATE WELL LOCATION, AS ABOVE, WITH DEEP WELL CORED

Figure 1
Water Table Map

advanced into the well field, blending alone did not appear to be sufficient to maintain adequate water quality.

As part of the Focused Feasibility Study, an endangerment assessment was conducted to determine the risk that water from the well field would present. This assessment considered the human health risks presented by supplying the peak demand using the least contaminated wells in the field. The human health risks were considered to be the sum of the cancer risk levels posed by individual carcinogenic or suspected carcinogenic compounds. The cancer risk level under these conditions in January, 1984 was estimated to be 5×10^{-6}. The endangerment assessment went on to consider the potential human health risks under conditions expected in the summer of 1984 with no remedial action. The cancer risk level was conservatively estimated to become about 4×10^{-5}.

This endangerment assessment showed that continued deterioration of the well field would pose an unacceptable threat to human health. The trend of the plume, as described above, indicates that contaminant levels would most likely increase. As a result of the above risk calculations and the historical trend, the authors found the "no action" alternative unacceptable.
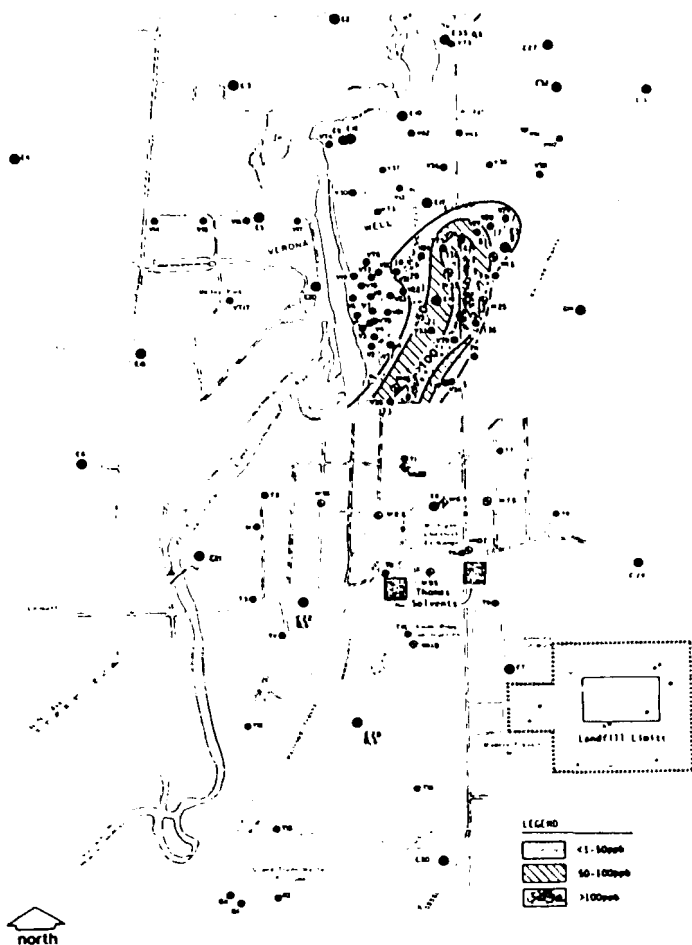
Figure 2
Contaminated Well Field Area Total VOC 1/82–4/82
Verona Well Field

Figure 3
Water Table Map February 1, 1984
Verona Well Field

IDENTIFICATION OF ALTERNATIVES

The need for an IRM was established to protect human health. The following performance criteria was established to evaluate the remedial action alternatives:

• Capable of providing safe potable water considering that all contaminant source locations had not been identified

• Capable of being implemented in a short time period (less than 4 to 6 months)

• Capable of meeting state environmental policies

• Consistent with potential long term remedies

The Focused Feasibility Study identified and evaluated many al.-ternatives for providing a potable water supply for the city. However, to meet both the time schedule and consistency with potential final remedies, it was decided all or a portion of the supply would be needed from the existing well field. Wells V13-V16, V37 and V39-V43 had been relatively free of contamination through the date of the study, and if concentrations did not increase they could supply water with concentrations well below the 10^{-6} cancer risk levels. This capacity would meet the average daily demand for 1982 and 1983 but would fall nearly 6 mgd short of meeting the 1983 maximum daily demand (18.5 mgd). From this information, the following 3 alternatives were developed and considered for detailed analysis:

(1) Treatment of contaminated water at the well field to meet the maximum daily demand (up to 18.5 mgd)

(2) Development of 6 mgd capacity in new wells north of the Verona Well Field and use of uncontaminated and/or slightly contaminated Verona Field wells

(3) Development of 12 mgd capacity in new wells greater than ½ mile north of the Verona Well Field

Need for a Purge System

Each alternative relied on a portion of the supply from existing uncontaminated or slightly contaminated wells. Therefore, pumping contaminated water from a line of purge wells near the northern edge of the more contaminated zone was needed for Alternatives 2 and 3 to arrest or restrict the spread of contamination. A purge system incorporated as part of Alternative 1 would also be desirable to limit the volume of water needing treatment. The selection of the municipal wells for the purge system had to consider the location of the contaminant sources as interpreted primarily from water quality within the well field. The progress of the source investigations was sufficient to provide indications on where some sources were located but was not sufficient to identify each source or the total distribution of contaminants throughout the aquifer.

Therefore, the wells selected for the purge system had to be located near the northern edge of the contaminant plume in order to intercept all likely sources. The wells selected for the purge system were wells V20, V22, V25, V27 and V28. These wells total 1950 gal/min in capacity and form a line along the northern edge of the more contaminated portion of the plume.

Disposal of Purge System Water

The 1950 gal/min of water to be pumped from the purge system could be disposed of in several ways. Each would require different levels of treatment ranging from no treatment to very high removal efficiency. The alternatives considered were:
- City of Battle Creek wastewater treatment plant
- Battle Creek River
- City's domestic water supply

Disposal to the Battle Creek wastewater treatment plant was eliminated because of limited sewer capacity in the area and time required to assess the potential impact of contaminated water on the treatment plant performance.

Direct discharge of VOC-contaminated water to the Battle Creek River would not meet discharge requirements established by the MDNR. The state requires that discharges to surface water must meet Best Available Treatment Economically Achievable (BATEA). For this situation, BATEA was defined by MDNR as 95% removal of VOCs using air stripping. Costs estimated for the air stripper (Table 2) show the capital costs in year 0 and operation and maintenance (O & M) costs over a 5-year period. The air stripper exhaust air is considered a source of VOCs by MDNR and was required to have 90% of the VOCs removed from the air emissions. The design influent, effluent, degree of removal and uncontrolled air emissions are shown in Table 3. Because of the MDNR requirements, costs for the air stripper included vapor phase carbon adsorption for the air stripper emissions.
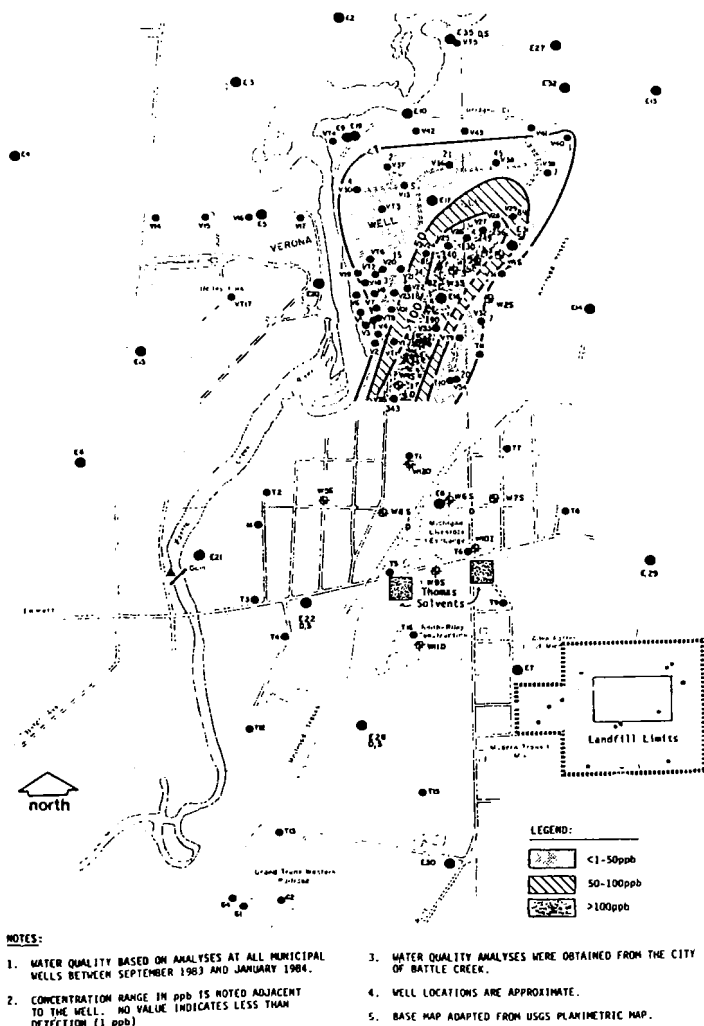
The present worth assumes a 5-year life, salvage value equal to demolition and future costs discounted at 10%. Since Michigan law requires use of air emission control equipment, $2 million will be used in the rest of this study for the 5-year present worth cost of air stripping as a treatment for river discharge. The alternative for disposal/use in the City's domestic water supply is discussed in the following section, Comparison of Alternatives.

COMPARISON OF ALTERNATIVES

Three water supply alternatives were identified above and are shown in Table 4. These alternatives were evaluated on the basis of six criteria. Each of these criteria and results of the comparisons are shown in Table 4 and are discussed in the section following this table.

Cost

The 5-year present worth cost of each alternative is presented in Table 4. Computation of present worth was based on a 10% discount rate and neglected any salvage value. Costs of each alternative include those for pumping and treating of the purge system water ($2,000,000).

Alternative 1
The cost for alternative 1 assumes:
- 13 mgd is available from slightly or uncontaminated wells which would not require treatment, the remaining 6 mgd (4200 gal/min) would come from treated sources
- 25% of the time, city demands would be supplemented by water produced by the purge system (1950 gal/min). The water treated

Table 2
Air Stripper Cash Flow Table

Year	Air Stripper w/o Emission Control	Air Stripper with Emission Control
0	$464,000	$ 675,000
1	70,000	442,000
2	70,000	442.000
3	70,000	442,000
4	70,000	442,000
5	70,000	442,000
Total Cost	$814,000	$2,885,000
Present Worth	$729,000	$2,350,000

Table 3
Predicted Operating Performance of Air Stripping Column

Compound	Design Influent* Concentration ug/l	Predicted Effluent Quality ug/l	Expected % Removal	Uncontrolled Air Emission mg/m³	lb/day
1,1 DCA	38	2	(94%)	1.8	0.8
1,2 DCA	8	6	(30%)	0.1	0.1
1,1,1 TCA	150	14	(91%)	6.8	3.2
cis 1,2 DCE	229	2	(99%)	11.3	5.2
1,1 DCE	11	--	(99%)	0.6	0.3
TCE	62	2	(97%)	3.0	1.4
PCE	94	3	(97%)	4.6	2.1
Total	592	29	(95%)	28.2	12.9

*Highest Concentration of each contaminant observed to date in any municipal well.

Figure 4
Contaminated Well Field Area
Total VOC 9/83-1/84
Verona Well Field

NOTES:
1. WATER QUALITY BASED ON ANALYSES AT ALL MUNICIPAL WELLS BETWEEN SEPTEMBER 1983 AND JANUARY 1984.
2. CONCENTRATION RANGE IN ppb IS NOTED ADJACENT TO THE WELL. NO VALUE INDICATES LESS THAN DETECTION (1 ppb)
3. WATER QUALITY ANALYSES WERE OBTAINED FROM THE CITY OF BATTLE CREEK.
4. WELL LOCATIONS ARE APPROXIMATE.
5. BASE MAP ADAPTED FROM USGS PLANIMETRIC MAP.

LEGEND:
<1-50ppb
50-100ppb
>100ppb

by air stripping would have to be polished to 99% removal using carbon adsorption
- 5% of the time, 2500 gal/min of more contaminated water would have to be treated using activated carbon adsorption

A carbon usage rate of about 2 lb/1000 gal would achieve an additional 95% removal on the treated purge system water at the effluent concentrations shown in Table 5. Treatment of the untreated higher concentration water (5% of the time at 2500 gal/min) is estimated to consume about 3 lb of activated carbon per 1000 gal treated. At a replacement carbon cost of $1.50/lb, an annual operation and maintenance cost of $700,000/year is estimated. The estimated capital cost for the system including a building for year round operation is $2,900,000.

Alternative 2

In this alternative, new wells of 6 mgd capacity would be installed approximately one-half mile north of the Verona well field. These new wells would be used preferentially to meet water demand with existing municipal wells used as needed.

Estimated capital costs for this alternative are $1,100,000. O&M costs associated with this alternative would be negligible.

Alternative 3

In this alternative, new wells totalling 12 mgd capacity would be installed and pumped in preference to existing wells. As a basis for estimating, 6 mgd of capacity is located one-half mile north as in Alternative 2, and 6 mgd of additional capacity is located approximately one mile north of the well field.

Estimated capital costs for this alternative are $2,800,000. O&M costs would be negligible.

Likelihood of Preventing Contaminant Spread

Alternative 1 is the least likely to prevent spread of contaminant into slightly contaminated and uncontaminated wells because the alternative would require continuous pumping of those wells to minimize costs of treatment. Alternative 3 would provide the greatest chance for success since it relies the least on pumping of existing wells close to the blocking wells and thereby gives the blocking wells a better chance to halt the spreading plume.

Time Required for Implementation

The air stripping system with air emission control would require the longest time to implement—4 to 6 months from the start of the design. Since this is common to all alternatives, the time factor is equal for all.

Complexity to Implement

Alternative 1 would be the most complex to implement due to the number of treatment processes involved and measures required to assure suitable quality of the treated water.

Environmental Impact

All three alternatives were judged to be equally low in potential for environmental impact.

Community Impact

No significant difference in community impact was recognized between the alternatives.

Based on the information summarized in Table 4, it is apparent that alternative 2 is equal to or superior in all aspects to Alternatives 1 and 3, with one exception: the expected reliability of the purge system to completely block flow of contaminants to the north is somewhat lower under Alternative 2 than Alternative 3. However, based on preliminary flow modeling, it was estimated that the purge wells may form a depression, with a low divide north of the purge wells, prohibiting flow to the north.

System Implementation

The Focused Feasibility Study (FFS) described in the first portion of this report and the REcord of Decision (ROD) identified

Table 4
Comparison of Water Supply Alternatives

Description	1 Treat Water for Potable Use	2 6 mgd new Capacity	3 12 mgd new Capacity
Cost[1] (5-year present worth @ 10% discount rate)	$7,600,000	$3,100,000	$4,800,000
Likelihood of preventing spread of contaminants	Low	Moderate	High
Time required for implementation	4-6 Months	4-6 Months	4-6 Months
Complexity to implement	High	Moderate	Moderate
Environmental impact	Low	Low	Low
Community impact	Low	Low	Low

[1]Cost of each alternative includes $2,000,000 cost of purge water treatment system

Alternative 2 as the preferred alternative. During development of the FFS, the contaminant concentrations continued to increase in municipal wells north of the proposed purge line, jeopardizing the potential success of the proposed IRM. Therefore, the USEPA implemented an Immediate Removal Action to initiate the purge system using an aqueous phase carbon adsorption system. This rapid installation system would enable the purge system to operate before summer peak pumping demands. A cone of depression could be developed around the purge well system during lower pumping stress to the north; reversal of flow of contaminants which had already migrated past the purge well line could begin.

The emergency purge well treatment system funcing and design was initiated on Apr. 20, 1984. Operation of the system began on May 25, 1984. The Initial Remedial Measure funding and Focused Feasibility Study began on Feb. 29, 1984. The Record of Decision (ROD) was completed by the USEPA, and the IRM was approved for funding by the Region V, USEPA Office on May 1, 1984. Three additional wells designed to provide 6 mgd were installed and began pumping to the distribution system on July 9, 1984. The air stripper with the air emission carbon adsorption system was installed and tested on Aug. 10, 1984 with start up planned as soon as the emergency carbon adsorption system tanks indicate breakthrough.

SYSTEM EFFECTIVENESS

The installed and operating system consisted of 3 wells designed to provide 6 mgd of the base water demand and a purge system using 4 or 5 municipal wells with a temporary carbon adsorption treatment system. At the time of this report (August, 1984), the total system has been operating for approximately 3 months, and its effectiveness is discussed below. The permanent (5-year expected life) air stripper with emission control treatment system is tested and ready to go on line. Therefore, the effectiveness of this treatment system has not been evaluated during daily operations.

The effectiveness of the 3 new wells can be measured by the fraction of the designed flow the wells are producing. The wells were planned to be placed adjacent to the Battle Creek River to obtain the maximum induced flow from the river. However, because of the wetland conditions and flood plain restrictions adjacent to the river, the wells were placed further from the river. Regardless of this less desirable location and modifications to the expected design, the wells are producing 85 to 95% of the designed production (5.1 to 5.7 mgd of the 6 mgd design capacity).

The effectiveness of the purge system can be measured by the changes inwater quality in the northern production wells (V30 and V38 through V43) and, secondarily, by the presence of a distinct

cone of depression around the purge wells. Because the purge system has been operating since May 25 and water quality is available through Aug. 7, only preliminary indications using water quality data can be made. The change with time of total VOCs at three wells north of the purge system, Wells V30, V38 and V39 is shown in Figure 5. Prior to the start-up of the purge system (May 25, 1984), concentrations were generally increasing; after start-up of the purge system, a noticeable downward trend occurs in each well. The trend is admittedly short-lived at the time of this report. Additional sampling is continuing. In addition to the short-term downward trend in concentrations, a preliminary water table map for August, 1984 (Figure 6), indicates a cone of depression may be centered around the purge well line. This distinct cone of depression around the purge wells would prevent migration of contaminants beyond the purge system.

CONCLUSIONS

- The hydrogeologic information that supported the IRM was based primarily on the water quality monitoring of the municipal wells, although additional hydrogeologic data from numerous monitor wells provided important supporting data.
- Relatively rapid contaminant migration to previously unaffected wells initiated the need for the IRM.
- The FFS considered several options in detail to determine the cost effectiveness, compatibility with potential long term remedies among other criteria.
- The IRM, ROD and emergency measure were expedited so that the purge system for blocking further contaminant migration was implemented in three months.
- The entire IRM was operational less than 5 months after worsening conditions dictated the need for it.
- The purge system appears to be functioning better than anticipated in blocking continued migration of contaminants.
- After less than 2 months of operation of the IRM, the city is receiving water with no detectable VOCs.

REFERENCES

1. CH2M HILL Inc., *Focused Feasibility Study, Verona Well Field, Battle Creek, Michigan*, Public Comment Draft, Mar. 28, 1984.

2. Vanlier, K.E., *Groundwater Resources of the Battle Creek Area, Michigan*, Water Investigation 4, Michigan Geological Survey Division, 1966.

NOTES:
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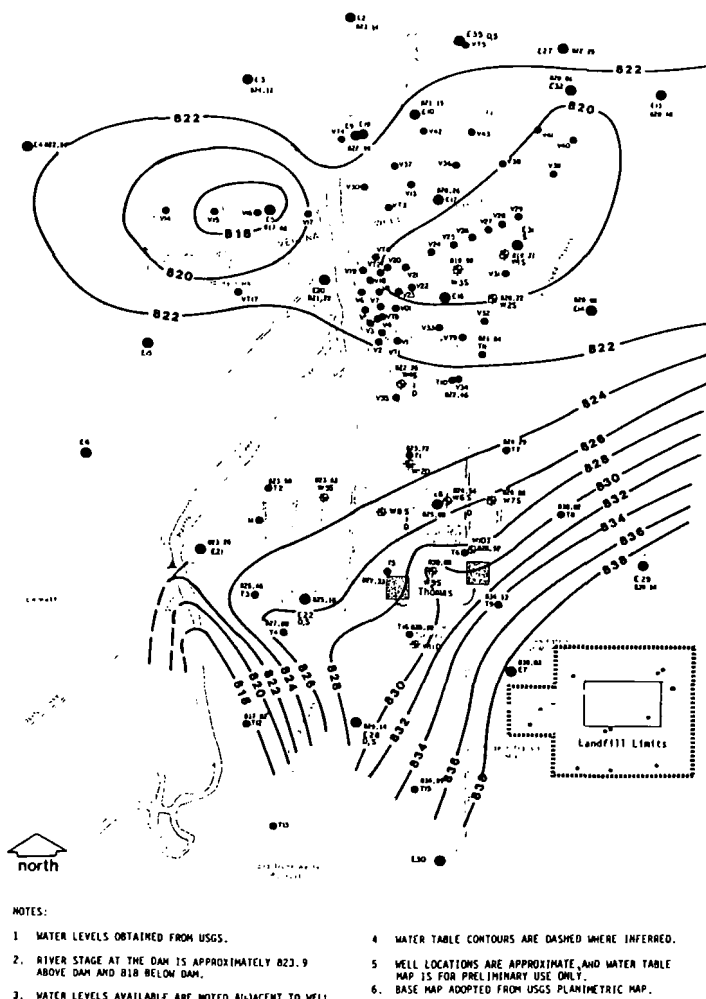
Figure 6
Water Table Map, August 1984, Verona Well Field
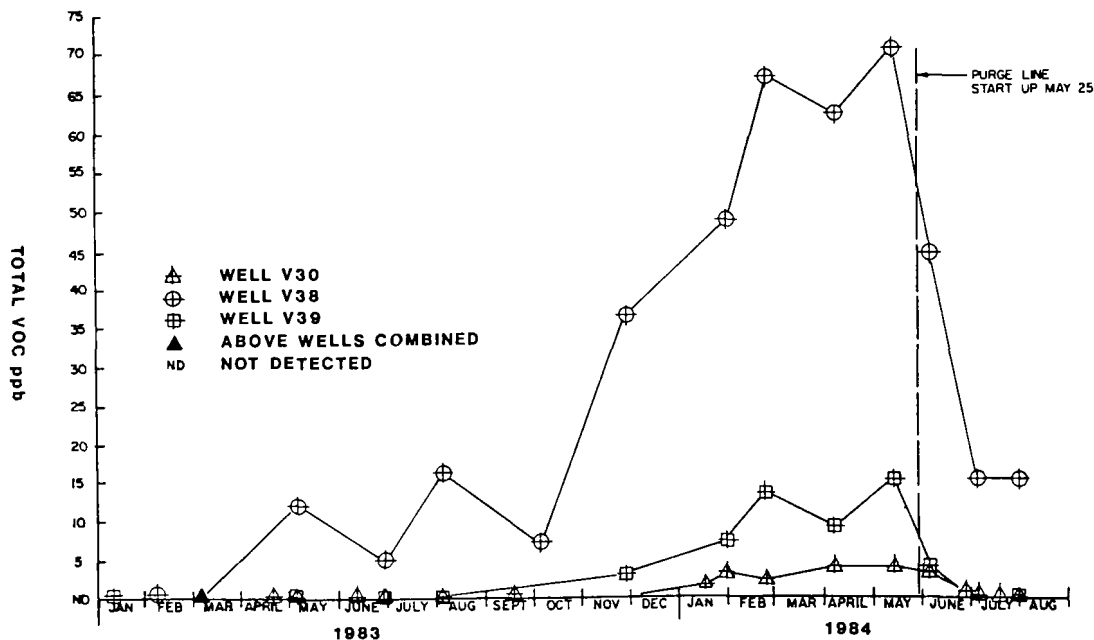
Figure 5
VOCs Graph, January 1983 to Present, Verona Well Field

CONTROL OF ORGANIC AIR EMISSIONS FROM GROUNDWATER CLEANUP — A CASE STUDY

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INTRODUCTION

An accidental spill of reagent grade monochlorobenzene (MCB) occurred while workers were filling a railroad tanker car at Standard Chlorine of Delaware, Inc. (SCDl), located in Delaware City, Delaware. An inventory analysis indicated that the volume of MCB discharged to the ground surface could have been as much as 5,000 gal. Since the specific gravity of MCB is 1.1066, it will sink through a soil or water column as a coherent "slug".

The spill occurred during a rainstorm, and part of the spillage ran off in surface ditches toward a creek running adjacent to the property. Prompt action by plant personnel and the Delaware Department of Natural Resources and Environmental Control (DNREC) (installing dams and pumps), resulted in the recovery of most of the runoff portion of the spill.

MCB-contaminated soils from the ditches were excavated and disposed of under the supervision of the State DNREC. A limited test boring, soil sampling and analytical program conducted by the plant in the immediate area of the spill indicted the presence of MCB to depths up to 40 ft below grade. The data gathered from this program led the plant and regulatory personnel to the conclusion that the potential for groundwater contamination existed. SCDI retained Roy F. Weston, Inc. (WESTON) to provide technical services in defining the extent and magnitude of the problem and in developing cost effective remedial action alternatives.

The purpose of this paper is to report on the successful collaboration of private industry, State regulatory personnel and consulting scientists and engineers in evaluating this problem and arriving at cost-effective, environmentally sound and regulatorily acceptable solutions to the problem.

HYDROGEOLOGIC INVESTIGATION

Description of Site

The plant lies in the Atlantic Coastal Plain of Delaware. The surficial sands of the Pleistocene age Columbia Group[1] unconformably overlie the Cretaceous age Potomac and Merchantville Formations. The Potomac Formation is underlain by bedrock. The Potomac Formation consists of clay and silt interbedded with sand and some gravel.[2] The upper zone of the Potomac is dominantly high-plastic clays (CH) with recorded thicknesses of up to 125 ft. The lower zone of the Potomac is dominantly fine sand to gravel and forms the major regional aquifer. A search of published literature of the area indicated: (1) the presence of only two actively pumping wells constructed in the Columbia Formation within one mile of the spill area; and (2) the Potomac Formation is a continuous confining layer beneath the plant site to a distance of about

one mile in all directions. Red Lion Creek runs along the north side of the plant property and drains into the upper Delaware Bay.

Subsurface Exploration and Monitor Well Installation

This program was conducted in two phases. During Phase I, ten monitoring wells were installed. Based on Phase I results, a Phase II program was undertaken; 21 exploratory borings and ten additional monitoring wells were drilled on or near the plant property (Fig. 1).

All exploratory drilling was accomplished using conventional hollow-stem auger equipment, and all wells were installed using mud-rotary equipment. All monitoring wells were constructed of galvanized iron pipe and well screens due to the incompatibility of MCB with polyvinylchloride.

The wells were drilled to the top of the Merchantville Formation or to the top of the Potomac clay, whichever occurred first. The stratigraphic logs confirmed at least 4 ft of the confining Potomac Clay in all 31 borings at an average depth of about 70 ft. The Merchantville Formation, with an average thickness of 13 ft, was confirmed in 17 of the 31 borings and apparently has been eroded away locally in the vicinity of the plant. The results from the test boring program indicated that the Potomac clay would form an effective barrier to the vertical migration of any contaminants present from the Columbia into the underlying aquifer sands.

A topographic map of the surface of the Potomac and Merchantville Formations is shown in Figure 1. North of the plant, a steep erosional gully occurs in the pre-Columbia surface centered on Boring TB-41. The location of the Merchantville Formation on the west of the plant is also shown in Figure 1.

The configuration of the surface of the Cretaceous age formations could influence the direction of migration of groundwater contaminants. A cross-section through the main plant area, paralleling the principal flow direction for groundwater in the Columbia sand and showing the key stratigraphic relationships, is given in Figure 2.

Water Quality Sampling and Analysis

All monitoring wells installed at the plant were sampled approximately 2 weeks after completion of well construction development. A Kemmerer sampler was used to collect a water sample from the bottom one foot interval from each well to obtain a worst case estimate of contaminant conditions. The concentrations of the major benzene species are shown in Table 1. These data were used to draw the isoconcentration map shown in Figure 3. The map illustrates the distribution of total benzene species detected, or the
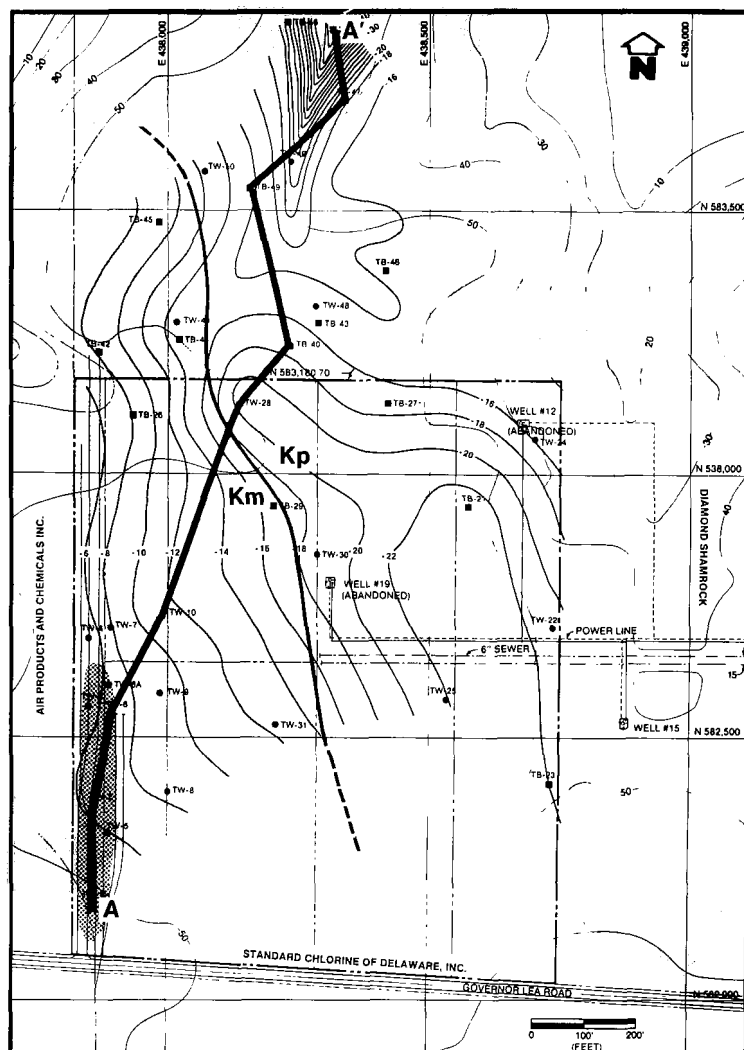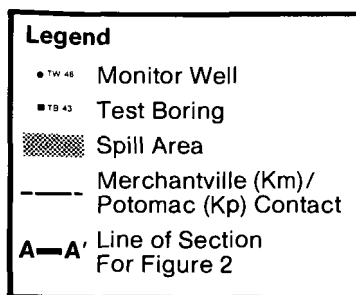
Figure 1
Topographic Map of Cretaceous Surface (MSL Datum). Dot Pattern
Indicates Area of Merchantville FM. Subcrop. Map Also Illustrates
Locations of all Test Borings and Monitor Wells

Table 1
Summary of Benzene Species Concentrations in the Groundwater (mg/l)

Well No.	Benzene	Mono-	o-dichloro	p-dichloro	1,2,4-trichloro
1	ND	60.0	12.4	7.8	10.2
2	ND	ND	ND	7.2	ND
3	ND	9.3	ND	6.1	7.0
4	11.0	9.3	ND	6.3	ND
5	66.8	300.0	144.0	51.9	163.0
6	ND	27.0	32.3	9.7	10.3
7	ND	28.9	17.8	28.6	7.1
8	206.0	134.0	40.5	18.0	9.8
9	166.0	134.0	35.9	12.2	9.4
10	107.0	117.0	86.9	49.4	24.3
22	ND	ND	ND	5.2	5.6
24	ND	18.7	8.2	9.5	9.4
25	ND	10.1	8.3	14.1	7.1
28	129.0	176.0	57.7	76.2	23.5
30	123.0	107.0	36.2	35.9	12.8
31	48.5	17.8	10.3	10.2	7.1
44	60.2	58.3	17.6	28.0	5.7
48	194.0	118.0	28.1	32.9	7.4
49	86.5	132.0	34.3	43.7	11.7
50	136.0	94.8	21.6	20.0	5.8

*ND means not detected.

row-sums from Table 1. Contaminants appear to be migrating in a generally northerly direction in a fairly cohesive plume, and the influence of pre-Columbia topography upon that migration pattern does not appear to be significant.

Hydrogeological Analysis

Water levels have been measured in the 20 monitoring wells periodically since their construction. The data gathered on June 23, 1983, were used to draw the water table contour map shown in Figure 4; the map shows that the dominant water table flow direction at the plant is northerly. This is illustrated by the selected flow net rays shown on that figure.

Comparison of Figure 4 with the isoconcentration map shown in Figure 3 indicates the groundwater flow direction at the plant is exerting the major influence over the observed contaminant migration pattern.

Of critical importance are the control of further migration of contaminants and the recovery of these contaminants from the groundwater flow regime. Physical methods for containment of the migrating contaminants, such as bentonite slurry walls, were evaluated but were dismissed from further consideration due to technical difficulty in construction, integrity of the technology in this application and costs. Since any physical barrier would have to be accompanied by recovery of contaminants at pumping wells and treatment at the surface, hydrodynamic barrier controls were considered to be the most appropriate technology to apply at SCDI.

Figure 2
Cross-Section Parallel with Principal Flow Direction
(See Figure 1 for Location)

Figure 3
Isoconcentration Map for Total Benzene Species Detected (mg/l)
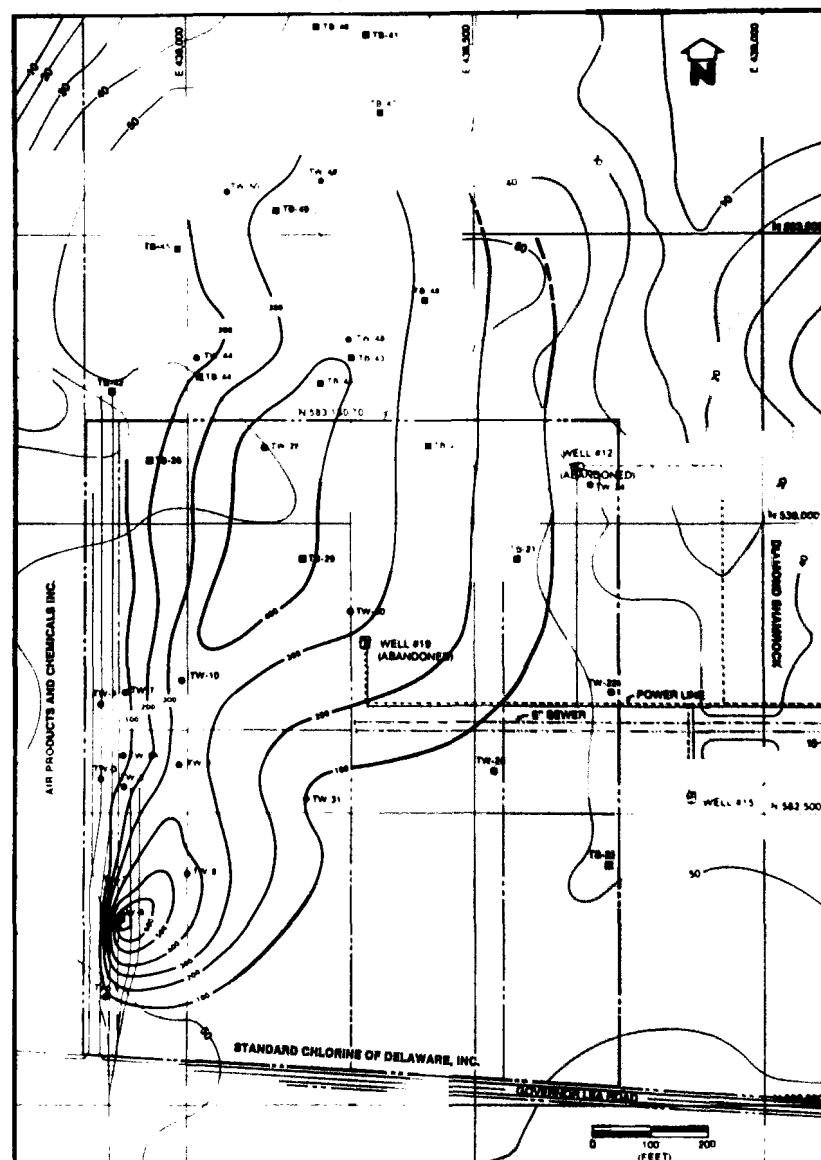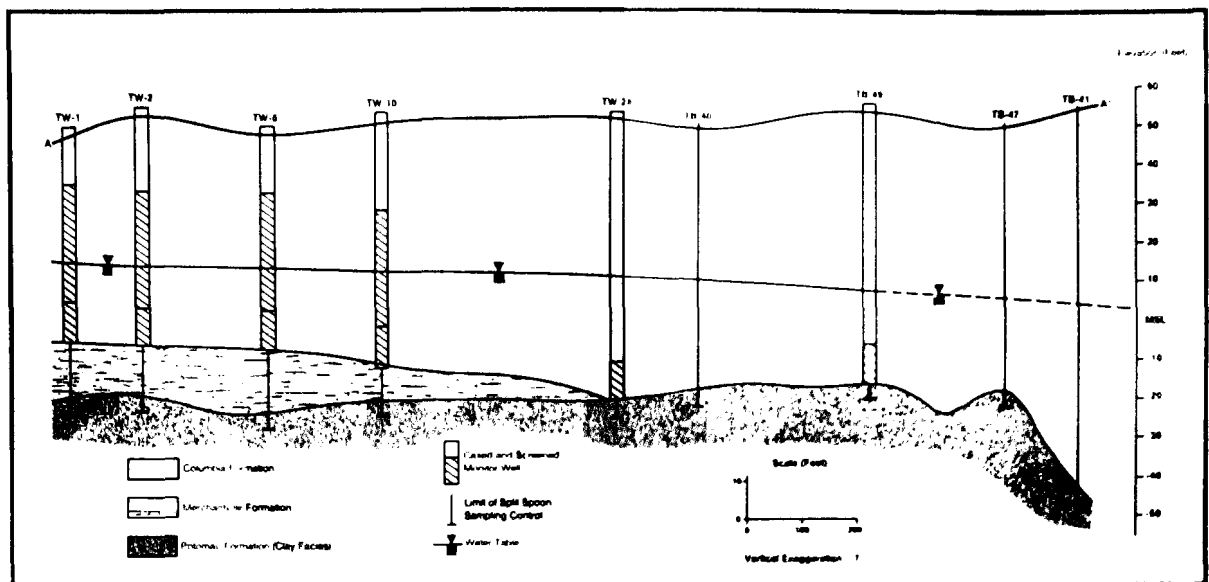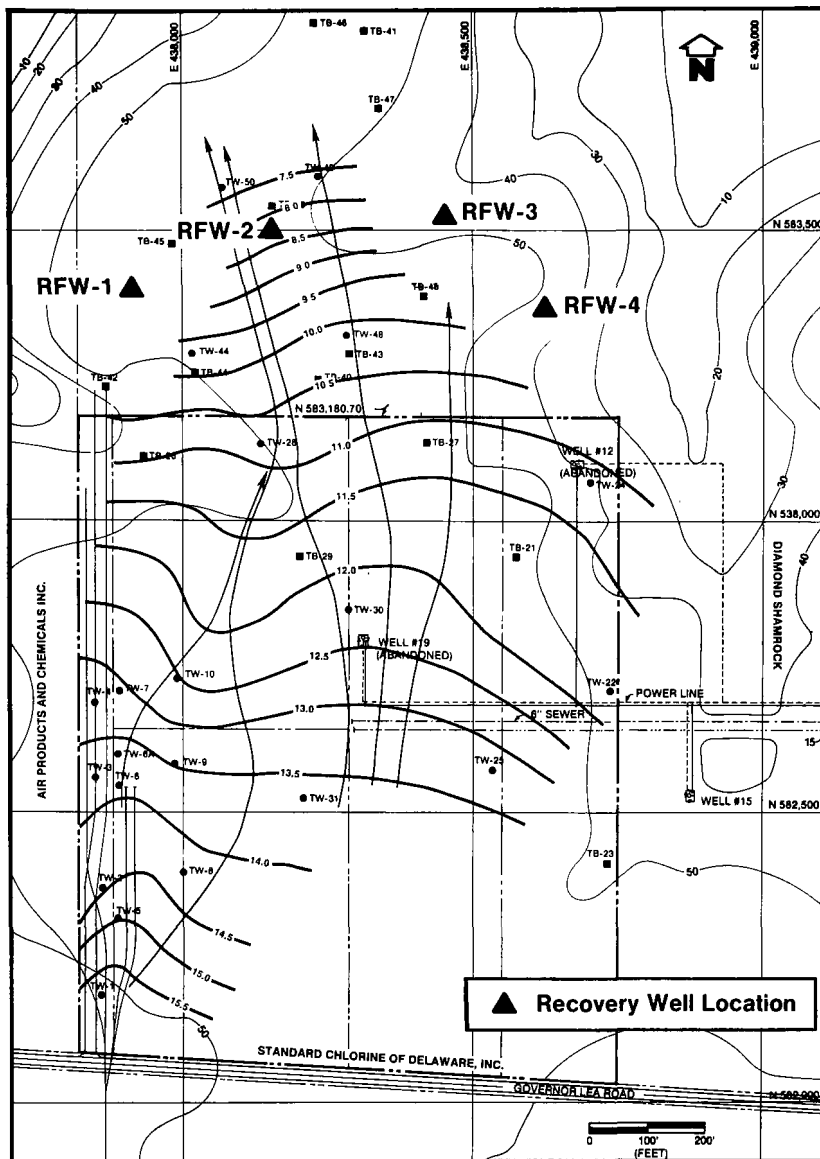
Figure 4
Water Table, 23 June 1983. Locations of Proposed
Recovery Wells Are Also Shown

During the Phase I operations, a pump test indicated that the transmissivity of the Columbia Formation ranged from 27,500 to 66,000 gal/day/ft. Seepage velocities computed from these values ranged from about 1.2 to about 10.2 ft/day and averaged about 3.6 ft/day. These data were used to design a barrier control and recovery pumping well field for the SCDI plant site. At a nominal pumpage rate of 40 gal/min/well, it was determined that four pumping wells would be needed to control further migration of the contaminants toward Red Lion Creek.

The recovery wells were constructed at the four locations shown shown on Figure 4. Each well was drilled using a cable tool drill and was constructed using an 8-in. diameter casing and a telescoping 8-in. diameter stainless steel screen. Each well was equipped with a vertical turbine pump of all brass, bronze or stainless steel construction with cast iron bowls.

While the design basis for the recovery well field was 40 gal/min/week, each pump has the capacity to pump up to about 100 gal/min. It is anticipated that the maximum combined pumpage rate needed to intercept and recover the groundwater contaminants would be about 250 gal/min. This pumpage rate provided the basis for the evaluation and design of the treatment facilities discussed in the following section.

CONCEPTUAL ENGINEERING INVESTIGATION

Evaluation of Options for Groundwater Treatment

Insufficient data were available to predict performance of the existing wastewater treatment plant at higher than current flows and contaminant loadings, and certain elements of the existing plant (such as the wastewater clarifier) would be hydraulically overloaded at an excess flow of 250 gal/min. Therefore, WESTON investigated several other options for treatment of recovered groundwater.

Air Stripping. Option 1 consisted of a packed tower which was used to air strip the benzenes out of the groundwater down to a level of 2.5 mg/l in the tower effluent. The effluent would then proceed, as shown in Figure 5, through a 100,000-gal flow equalization and stripping tank and would be split between two clarifiers, one existing and one new unit, both the same size. The clarified effluent would then flow through a filtration unit and then to the effluent flume. The 100,000-gal flow equalization and stripping tank would provide additional "polishing", and the clarifiers would remove biological and flocculated solids formed as a result of air stripping.

CONTAMINATED GROUNDWATER CONTROL   179
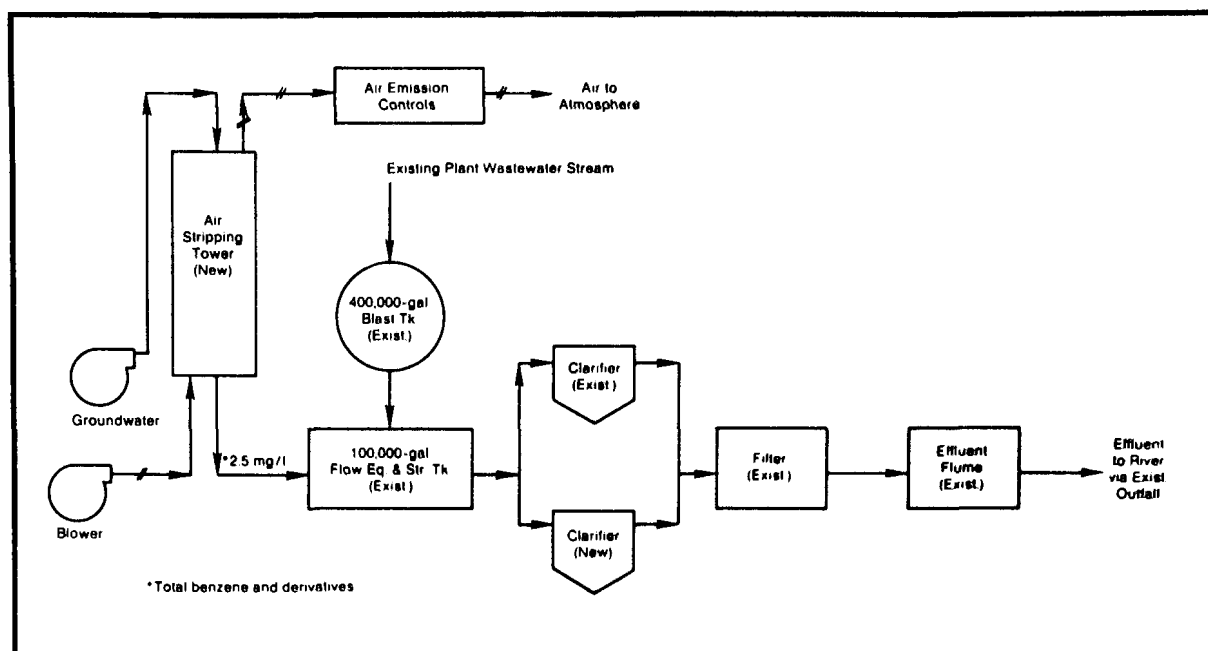
Figure 5
Groundwater Treatment Flow Diagram

The estimated emissions of benzene compounds to the air as a result of air stripping are shown in Table 2. Emissions at these levels would necessitate installation of air emission controls to limit air emissions to acceptable levels.

Steam Distillation. Option 2 consisted of a scaled-up, high-temperature, steam distillation system similar to that used for solvent recovery in the main plant. Estimated annual operating costs of this system would exceed $1,000,000, mainly for energy. This additional system would consume all the plant's standby steam generating capacity. Since this situation would be untenable for production, additional costs would be incurred in the construction of a separate, packaged boiler unit to power the steam distillation apparatus. Because of these excessively high costs, it was recommended that steam distillation not be considered further.

Activated Carbon Treatment. Option 3 consisted of direct treatment of pumped effluent in granular activated carbon (GAC) columns. Based on removal of total benzenes down to a level of 2.5 mg/l, WESTON estimated that the carbon requirement would be on the order of 33,000 ld/d a yr. Assuming that this carbon could be steam-regenerated in-place, as is currently done at SCDI, the average daily carbon loss during regeneration would be approximately 10%, or about 3,300 lb/day, At $1.00/lb, the annual cost for carbon replacement alone would be in excess of $1,200,000. Based on these excessively high costs, it was recommended that carbon treatment not be considered further.

Options 2 and 3, while technically viable, were eliminated from further consideration due primarily to excessively high costs. Option 1, Air Stripping with associated emission controls, was selected as the most efficient and cost-effective method for groundwatekr cleanup. DNREC concurrence in-principal with this system resulted in design of the basic treatment plant and evaluation of options to provide the necessary air emissions control.

ASSESSMENT OF AIR EMISSION CONTROL OPTIONS

Since uncontrolled emissions of benzene compounds to the atmosphere at the loading shown in Table 2 would be unacceptable to SCDI and to the DNREC, two control strategies were selected as technically feasible options to reduce air pollution:
•Air stripping with exhaust gases vented to a fume incinerator
•Air stripping with exhaust gases vented to an existing process boiler

Various alternative refrigeration and condensation processes were considered but were not feasible due to the low concentrations of benzene compounds in the air stripping tower off-gas.

Gas Venting to a Fume Incinerator (Option 1-1)

Factors influencing the efficiency of an incinerator are temperature, degree of mixing and residence time in the combustion chamber. Only enclosed combustion was evaluated for this option because open flares may only be 60% efficient for benzene destruction.[3]

Use of both a primary and a secondary combustion chamber will ensure a high degree of mixing, combustion zone temperatures in excess of 1,600 °F and a residence time of not less than 1 sec (Table 3). This conservative design should achieve at least 99% control of the chlorinated benzene compounds since these chemicals have autoignition temperatures of approximately 1,200 °F.

Gas Venting to an Existing Boiler (Option 1-2)

This option is similar to the first option, except that an existing 125,000 lb/hr process boiler would serve as the enclosed combus-

Table 2
Mass Emissions of Benzene Compounds from Air Stripping Tower

Compound	Mass Emissions of Pollutants		
	lb/hr	lb/day	tons/year
Benzene	13.6	326	59.6
MCB[1]	10.9	262	47.7
1,2-DCB[2]	4.5	108	19.7
1,4-DCB[3]	3.1	74	13.6
TCB[4]	2.2	53	9.6
TOTAL	34.3	823	150.2

[1]Monochlorobenzene or chlorobenzene (Formula: C_6H_5Cl).

[2]1,2-Dichlorobenzene or o-Dichlorobenzene (Formula: 1,2-$C_6H_4Cl_2$).

[3]1,4-Dichlorobenzene or p-Dichlorobenzene (Formula: 1,4-$C_6H_4Cl_2$).

[4]Trichlorobenzene (Formula: $C_6H_3Cl_3$).

Table 3
Design Data for Air Emission Control Options

Description	Design Data Option 1-1	Option 1-2
Combustor Type	Two Stage, Fume Incinerator	B&W Model FM-117-88C, Boiler
Type of Fuel	Natural Gas	Nat. Gas/No. 2 or No. 6 Fuel Oil
Burner Capacity	11×10^6 Btu/hr	160×10^6 Btu/hr
Combustion Zone Temperature	1,600°F	2,000°F
Residence Time	1 second minimum	1 second minimum
Emission Control System	Wet Scrubber	None
Design Control Efficiency	VOC's — 99% + HCL — 90%	VOC's — 99% + HCL — 0%

tion chamber. At the combustion temperatures and residence time shown in Table 3 for the Standard Chlorine process boiler, this system is expected to achieve a benzene removal efficiency as high as 99%.[4]

Babcock and Wilcox, the boiler manufacturer, indicated that the HC1 emissions would not cause a problem as long as the flue gas temperature remained above the acid dewpoint (which is expected to be between 300 and 350°F). This does not appear to pose a problem since the design economizer outlet temperature is 422°F and typical stack temperature is in excess of 350°F.

Air Quality

The estimated controlled air emissions for the two options are summarized in Table 4. The purpose of the air impact analysis was to ensure that the air pollution control systems under consideration are sufficient to minimize off-site ambient air impact. A dispersion modeling analysis was used to demonstrate that the ambient concentrations due to each option are below relevant health effects criteria levels.

Several different types of health effects can result from exposure to the substances listed in Table 4, including: long-term body burden exposure to carcinogens; long-term chronic exposure to non-carcinogens; short-term acute effects; and odor. The substance of greatest concern from a long-term carcinogenic perspective is benzene. The USEPA Cancer Assessment Group (CAG) has estimated the exposure level which relates to a 10^{-5} cancer risk at 0.208 ug/m³ of benzene.[5] When this body burden is corrected for the expected 10-yr project duration, as opposed to the assumed 60-yr life-time period, the acceptable exposure is six times higher than 0.208 ug/m³, or 1.25 ug/m³. For the long-term cumulative effects of the chlorinated benzene compounds, the best available exposure criteria are the Threshold Limit Values (TLV) corrected by some safety factor. This approach has been used in several states that have attempted to establish guidelines for toxic air pollutants. A typical safety factor which has been used in several of these guideline documents is the TLV divided by 420.[6] Weston applied this safety factor in this evaluation.

HC1 is a severe irritant which can cause short-term acute effects. The Philadelphia Toxic Air Pollutant guideline has set the same safety factor on HC1 exposure of the TLV/42.[7] Weston used that

Table 4
Summary of Estimated Controlled Air Emission Rates

Pollutant	Option 1-1 – Air Stripping/Fume Incinerator (lb/hr)	(ppm$_V$)	(g/sec)	Option 1-2 – Air Stripping/Process Boiler[1] (lb/hr)	(ppm$_V$)	(g/sec)
Particulates (TSP)	0.05	N/A	--	0.008	N/A	--
Sulfur Dioxide (SO$_2$)	0.006	0.09	--	0.001	0.003	--
Nitrogen Oxides (NO$_x$)	1.50	31.4[2]	--	0.217	0.87[2]	--
Carbon Monoxide (CO)	0.37	12.7	--	0.054	0.36	--
Hydrogen Chloride (HC1)	0.86	22.7	0.108	8.6	43.4	1.084
Volatile Organic Compounds (VOC's)						
- Benzene	0.14	1.72	0.017	0.14	0.33	0.017
MCB	0.11	0.94	0.014	0.11	0.18	0.014
1,2-DCB	0.05	0.33	0.006	0.05	0.06	0.006
1,4-DCB	0.03	0.19	0.004	0.03	0.04	0.004
TCB	0.02	0.11	0.003	0.02	0.02	0.003
Other Non-Methane VOC's	0.03	1.81[3]	0.004	0.004	0.05[3]	0.001
- Total VOC's	0.38	5.10	0.048	0.354	0.68	0.045

[1] Option 2 emission rates are based on incremental increases in emissions above the current boiler No. 3 emission rates.

[2] NO$_x$ ppm$_V$ concentrations are based on the molecular weight of NO$_2$ (46 lb/mole).

[3] Other VOC's ppm$_V$ concentrations are based on the molecular weight of CH$_4$ (16 lb/mole). These VOC's result from the combustion of natural gas and are nonhazardous.
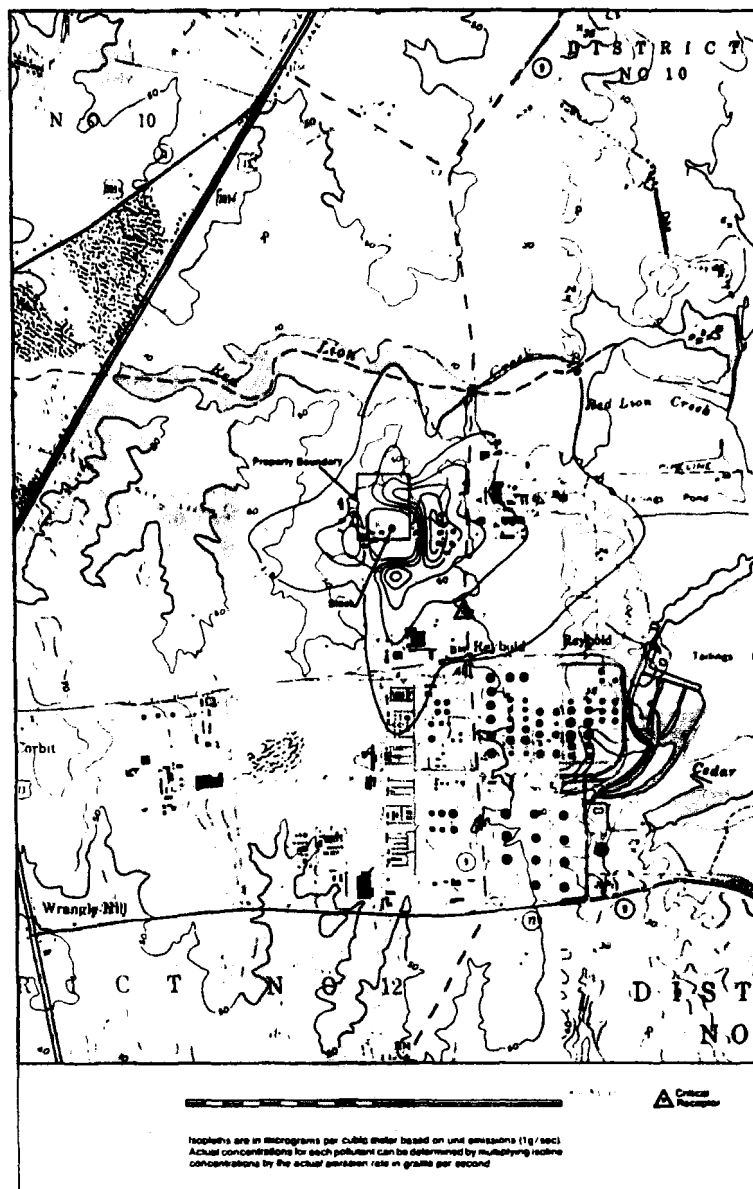
Figure 6
Isopleth Diagram of Ambient Concentrations Due to Air Stripping with a
Fume Incinerator for Control

Table 5
Predicted Average Annual Concentrations ($\mu g/m^3$) for Two Emission
Control Options Compared with Health Guideline Exposure Levels

Compound	Odor Threshhold	TLV/420	Option 1-1		Option 1-2	
			Peak Receptor	Critical Receptor	Peak Receptor	Critical Receptor
Benzene	516	71.4	0.013	0.003	0.111	0.048
MCB	972	833.3	0.011	0.003	0.091	0.039
1,2-DCB	305,000	714.3	0.005	0.001	0.039	0.017
1,4-DCB	90,000	1,071.4	0.003	0.001	0.026	0.011
TCB	--	95.2	0.002	0.001	0.020	0.008
HCL*	1,400	156	0.814	0.201	0.702	0.302

* TLV/42
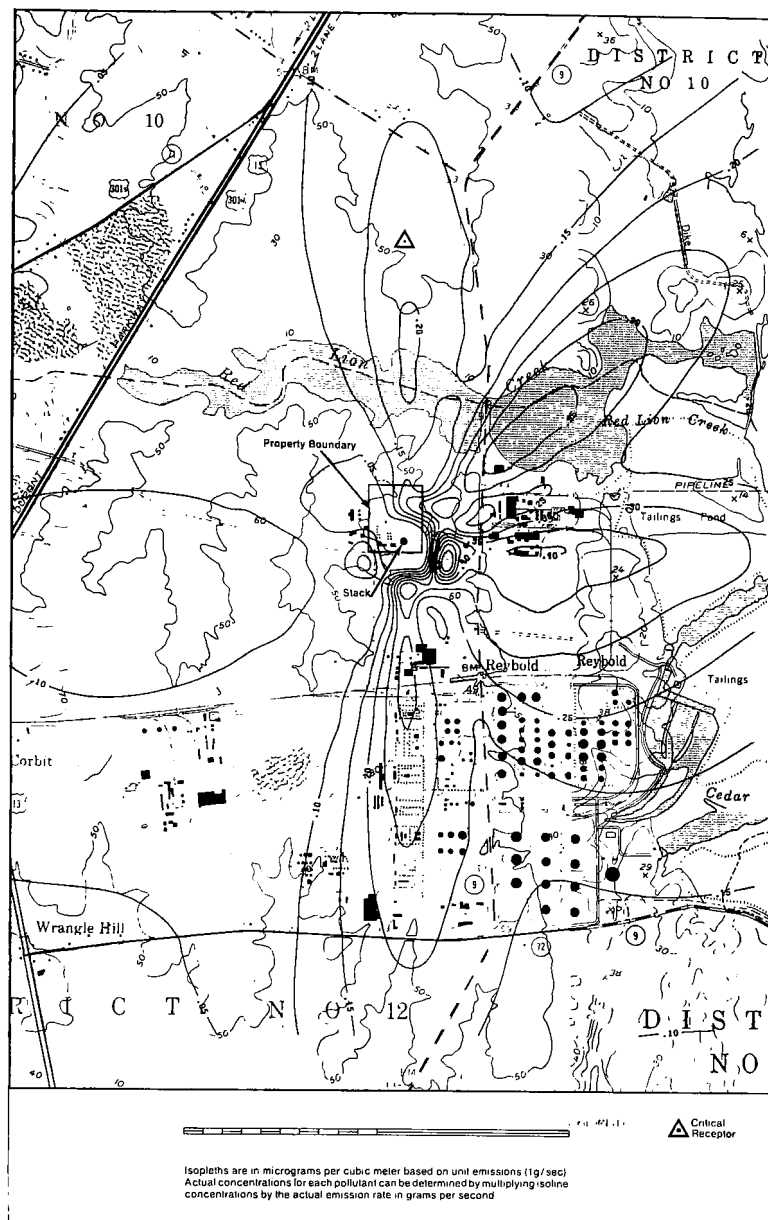
Figure 7
Isopleth Diagram of Ambient Concentrations Due to Air Stripping with a
Process Boiler for Control

same conservative approach in the determination of health effects from HCl exposure.

All substances listed in Table 4 were included in the modeling analysis; in certain cases, they are considered to be potentially hazardous. Criteria pollutants such as TSP (particulates), CO and SO_2 were not modeled since the controlled emission rates for either option are well below the PSD (prevention of significant deterioration) significance level and would be well below applicable standards.

A USEPA-approved UNAMAP screening model (PTPLU) was used to determine the downwind distance where peak concentrations would occur for a variety of meteorological conditions. Subsequently, this information was used to develop the source receptor grid network for use in a more refined UNAMAP model (ISCLT). The ISCLT model was used in conjunction with the 1965 through 1981 meteorological STAR distribution for Philadelphia to predict the annual ambient air quality impact due to emissions from both control options.

The Philadelphia meteorological data were used since they represent the closest and most complete data base available. A dense polar grid coordinate network with a grid spacing of 330 ft (100 m) to a downwind distance of 3300 ft. (1,000 m) for every 10 degrees

of arc, and with an expanded grid space of 25 ft (250 m) out to 8250 ft (2,500 m), was used in the modeling analysis. Since the height of the existing boiler stack is less than the Good Engineering Practice (GEP) stack height, the building downwash or wake effects option was used in the modeling analysis.

The results of the modeling analysis are presented in Table 5 for the two control options. The incinerator control option would result in concentration levels which are an order of magnitude below the CAG for benzene at the peak off-site receptor. All other predicted pollutant concentrations for benzene compounds are several orders of magnitude below the TLV/420 at the peak off-site receptor. The predicted concentration at the critical receptor (the nearest residence) is a factor of 26 below the CAG value for benzene. The TLV/420 values for the other benzene compounds are about 12,000 to 100,000 times greater than the predicted levels. The TLV/42 for HCl is 200 to 500 times greater than the predicted values at the peak and critical receptors. The odor threshold for all pollutants is also significantly greater than the predicted concentrations.

The boiler control option results indicate that ambient concentration levels would be a factor of about 100 to 180 below the CAG for benzene for the peak and critical receptors. The TLV/420 is predicted to be about 40,000 to 350,000 times greater than any pre-

dicted peak ambient concentrations for the chlorinated-benzene compounds. The TLV/42 for HCl is about 200 times greater than the predicted ambient levels at any receptor. The predicted values are also well below the odor thresholds for all compounds.

To provide a better understanding of the spatial distribution of ambient pollutant concentrations for each option, concentration isopleth diagrams were developed (Figs. 6 and 7). These figures show the concentrations which would occur if 1 g/sec of a pollutant were emitted (i.e., unit emissions) by the control options. Hence, to arrive at the concentration for any particular pollutant, the isoline concentration should be multiplied by the appropriate g/sec emission rates from Table 4. For example, the 0.1 µg/m³ isoline concentrations should be multiplied by 0.017 (from Table 4) to obtain the predicted ambient annual benzene concentration for the boiler control option isoline. The important point to note is how concentrations change as a function of downwind distance. Hence, the diagrams provide a better perspective on the spatial distribution of pollutant concentrations at any relevant receptor to appropriate health benchmarks.

The results of the modeling analysis indicated that either of the proposed control technologies would provide a substantial margin of safety over any health benchmark level based on an annual exposure criterion. Although the modeling analysis used predicted annual average ambient concentrations, a 24-hr peak concentration can be estimated by multiplying the average annual values by a factor of 10. This estimate is consistent with the USEPA guidelines for dispersion modeling. Since the predicted annual ambient concentration for any receptor or pollutant for either control option is at least a factor of 20 below any applicable health benchmark level, it is unlikely that the emissions due to the proposed control technologies would result in an exceedance of the benchmark for any 24-hr period.

Table 6

Description	Option 1 - Air Stripping/Fume Incinerator	Option 2 - Air Stripping/Process Boiler
Total Capital Costs		
- Air Stripping System	$ 166,000	$ 166,000
- Steam Stripping System	--	--
- Control System	$ 448,000	$ 45,000
TOTAL	$ 614,000	$ 211,000
Annual Operating Costs		
- Air Stripping System	$ 27,000	$ 27,000
- Steam Stripping System	--	--
- Control System	$ 514,000	$ 66,000
TOTAL	$ 541,000	$ 93,000
Total 10-Year Operating Costs	5,410,000	$ 930,000
Total 10-Year Costs	6,024,000	$1,141,000
Incremental Cost per Pound of Benzene Compounds Removed Over Uncontrolled Air Stripping	$ 2.03/lb	$ 0.38/lb

From an environmental point of view, the second option, air stripping with a process boiler for control of pollutant emissions, is more attractive. Although this option would result in air emissions, the magnitude of the controlled emissions would be small and the ambient air quality impact would be minimal. Comparison of the predicted ambient concentrations due to these emissions to all appropriate benchmarks of public health suggest that there would be no adverse effects due to implementation of this option. This condition would also be true for the first option, air stripping with a fume incinerator for control. Hence, from an environmental/health effects perspective, both options would be acceptable. Environmental permitting for chemical destruction in the boiler would be straightforward; however, the first would require a significantly larger permitting effort.

The economic impacts of the two options are quite different. From both a capital and an operations and maintenance (O&M)

point of view, the most attractive option is the process boiler control option. It has lower capital and O&M costs and a lower unit treatment cost.

Based on the above considerations, air stripping with a process boiler for control of air pollutant emissions was recommended. It would be the most economical option and would be acceptable from an environmental permitting and public health perspective. WESTON has recommended this option to SCDI which has, in turn, proposed this system to the Delaware DNREC. The DNREC has approved, and all parties are working together to obtain the other necessary permits so that cleanup can commence.

Recommendation of an Alternative Control Option

WESTON has prepared an estimate of the total capital costs and annual operating costs for each alternative control option (Table 6). To compare the two alternatives, the total capital costs were added to the total estimated operating costs over the life of the remedial action project (assumed to be 10 years). These total 10-yr costs (in constant 1983 dollars) were then divided by the total mass of additional benzene compounds removed to determine the net unit cost of the control option. As shown in Table 6, the second air pollution control option is more than five times more cost-effective than the first.

CONCLUSIONS

As a result of spills during the history of operation of the SCDI Plant, groundwater in the water table aquifer at the plant is contaminated with benzene compounds. SCDI has made the financial commitment to undertake cleanup of the water table aquifer. WESTON has provided expertise in evaluating the magnitude and extent of groundwater contamination and in evaluating a broad range of remedial action technologies which would be used to affect cleanup. A technically feasible, environmentally and regulatorily sound, cost effective set of control options has been recommended to SCDI and to the DNREC. The State has provided invaluable assistance and cooperation in working with the consultant and SCDI.

All parties have agreed in principal with the remedial actions recommended by the consultant and are currently working together to complete the permitting effort required for implementation. This project serves as a classic example of the benefits to be derived from cooperation and mutual assistance between government and private industry in achieving environmental quality goals.

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1. Jordan, 1976.

2. Pickett, 1970, *Geology of the Chesapeake and Delaware Canal Area, Delaware,* Delaware Geologic Survey, Geologic Map Series, No. 1, Scale—1:24,000.

3. "USEPA, Proposed National Emission Standard for Hazardous Air Pollutants—Benzene Fugitive Emissions", *Environmental Reporter,* Jan. 9, 1981.

4. "USEPA Proposed Standard for Benzene Emissions for Maleic Anhydrite Plants", *Environmental Reporter,* Apr. 18, 1980.

5. Cancer Assessment Group Values (CAG)—These are recommended lifetime exposure limits to known carcinogens which have been developed by the USEPA for a limited number of toxic compounds. The CAG number represents maximum allowable concentrations that may result in incremental risk of human health over the short-term or long-term at an assumed risk. This assumed risk (10^{-5}) is the expected number of increased incidences of cancer in the effected population when the concentration over a lifetime equals the specified value. The CAG values are listed in the "Land Disposal Toxic Air Emissions Evaluation Guideline" published by the USEPA in Dec. 1980.

6. This number related the TLV which assumes 8 hr/day, 40 hr/week exposure to 24 hr/day, every day exposure. In addition, it also includes a safety factor of 100.

7. Philadelphia Air Management Services, "Recommended Ambient Air Quality Guidelines for Toxic Air Contaminants," June 1983.

INPLACE CLOSURE OF PREVIOUSLY BACKFILLED AND ACTIVE SURFACE IMPOUNDMENTS

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INTRODUCTION

In-place closure should be evaluated as an option whenever other cleanup options would involve removal of more than just a few truckloads of waste and contaminated soil. Not only is removal expensive, but it also merely transfers the hazardous material and associated risk to a new site. The in-place closure option can include treatment of the waste and other contaminated media to render them nonhazardous.

In-place closure techniques can be used on impoundments that have either reached the end of their useful life or have been inadequately closed. The case history discussed here involves both of these applications for in-place closure:
•Two older impoundments, which had contained spent pickle liquor, had previously been inadequately closed by simply backfilling with soil (Fig. 1)
•Two large surface impoundments, also containing spent pickle liquor, were to be taken out of service and closed by simply backfilling with soil (Fig. 1)
Separate investigative approaches and closure plans were developed for each site. Following some background information, results of the investigations and progress toward final closure of both the active and previously backfilled impoundments are presented.

BACKGROUND

Impounded waste at the site had been generated by the pickling (scale and rust removal) of steel by dipping the metal in a bath of sulfuric acid. Typically, the acid bath was replaced when its iron content (from dissolved rust) reached 9 to 10%. The spent acid was simply pumped into the impoundments. The build up of solids eventually filled the impoundments, requiring new impoundments to be constructed.

All impoundments discussed in this report were constructed by simply bulldozing soil outward from what would be the middle of the impoundment. Soil removed from the middle was used to form the sidewalls and dikes. Prior to enactment of RCRA, impoundment closure was simply the reverse of impoundment construction, i.e., the dikes were bulldozed back into the impoundment.

Pre-RCRA closure regulations did not require a low permeability cap, a cover of topsoil or a permanent vegetative cover. Backfilling of the two older impoundments which were filled with acidic sludges resulted in subsidence of the backfilled material and oozing of the sludge to the surface. Subsequent rainfall resulted in erosion of the backfill and overland flow of the acidic materials. In addition, groundwater quality in the area of both the backfilled and active impoundments has been degraded.

Both the backfilled and active impoundments are located in a marine deposit consisting of clay. This soil contains small amounts of silt, sand, gravel, sandstone and iron ore. Below 5 ft, the soil contains many calcium carbonate concretions, masses of soft lime and some gypsum. A typical profile of the soil near the backfilled impoundments is described in Table 1.

Standard engineering interpretation of borings down to 7 ft would have suggested that the site was suitable for constructing impoundments. Hindsight would indicate that, considering the calcareous deposits, the site might fail to contain acidic wastes. Consideration of the profile characteristics below the 7 ft depth would also have indicated the potential for pollutant migration (Table 1).

ASSESSMENT OF THE BACKFILLED IMPOUNDMENTS

Objectives of the assessment associated with the previously backfilled impoundments included:
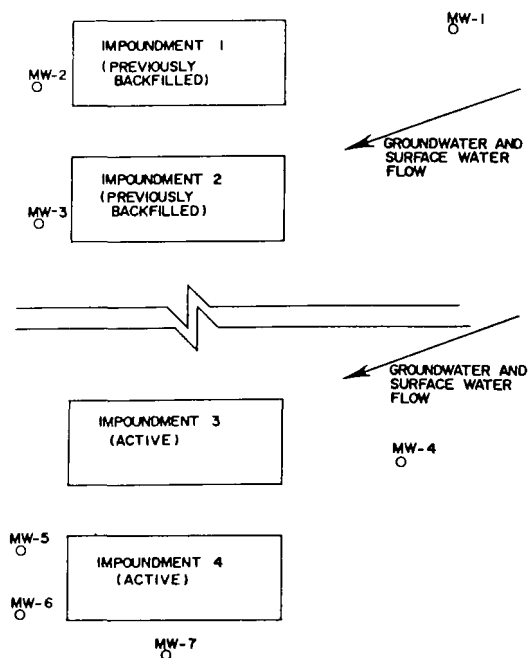
Figure 1
Locations for Monitoring Wells Associated with Active and Previously Backfilled Impoundments

Table 1
Typical Profile of the Soils Adjacent to the Impoundments

Depth (ft)	Liquid Limit	Plasticity Index	% Passing No. 200 Sieve	pH	Classification	Description
0.0- 1.5	58	27	26	6.0	GC	Brown Clayey Gravel
1.5- 3.0	68	44	56	7.2	CH	Tan and Red Clay Mildly Alkaline
3.0- 5.0	133	94	97	7.8	CH	Tan and Light Gray Clay Many fine CaCO₃ Concretions
5.0- 7.5	95	62	80	8.2	CH	Red, Tan, and Light Gray Clay Common CaCO₃ Concretions and masses of soft limestone and some gypsum
7.5- 9.0	50	25	20.0	7.2	GC	Tan Clayey Gravel
9.0-10.5	53	28	82	8.0	CH	Dark Gray Silty Clay
10.5-13.0	--	--	99	7.3	SM	Light Gray Gravelly Sand

1) A determination of the quality of groundwater leaving the site
2) A determination of the extent of soil contamination associated with the site
3) Development of a closure plan to correct problems associated with the previous inadequate closure

Previously backfilled impoundments (Nos. 1 and 2 on Fig. 1) originally occupied about 1.25 acres to a depth of about 7 ft below grade. Closure of these impoundments amounted to simply backfilling with a bulldozer. Consequently, some acidic sludges oozed to the soil surface. In areas where this occurred, surface soils had a low pH (3.2 to 3.8) and little vegetative cover. Topographically higher areas were partially vegetated while the lower areas had very little vegetation.

Several borings taken in and around the backfilled impoundments indicated residual acidity down into the groundwater; groundwater was usually encountered at a depth of 11 ft. A typical boring through one of the backfilled impoundments is shown in Figure 2. Soil pH in the backfilled impoundments ranged between 2.4. and 4.5. The lowest pH values occurred at the old bottom of these impoundments. The pH of the soil 3.5 ft below the old bottom was as low as 2.6. Soil at the groundwater level was generally around pH 4. At 13 ft, a calcareous pebble layer existed 1 to 2 ft below the groundwater level.

At pH values of less than 4.0, the lattice structure of clays will partially dissolve, releasing undissolved fragments for migration in a percolating leachate.[1] Acid wastes have dissolved smectitic, illitic and kaolinitic clay minerals.[2] Others have found that a combination of partial dissolution and piping of clay fragments due to exposure to acids can result in permeability increases in clay soils.[3]

DESCRIPTION	DEPTH (FT)	SYMBOL *
YELLOW-BROWN CLAY WITH 10% BLACK TOPSOIL (pH 3.0-3.4)	1	
GRAY-BROWN CLAY (pH 3.0-3.2)	2-3	
YELLOW-GRAY SLUDGE (WET)(pH 2.4-3.0)	4	
YELLOW-GRAY CLAY(MOIST)(pH 2.4-2.7)	5-6	
YELLOW-BROWN CLAY ,5-40% WHITE CONCRETIONS (pH 2.6-2.8)	7-8	
GRAY CLAY WITH WHITE GRAVEL (pH 2.8-4.0)	9-10	
GRAY GRAVELLY SAND (pH 4.0-4.5)	11-12	

* UNIFIED SOIL CLASSIFICATION SYSTEM

Figure 2
Soil Boring from Backfilled Impoundment 2

Samples taken at depths down to 5 ft around the perimeter of the backfilled impoundments indicated only a slight decrease in pH upslope. Similar samples taken downslope revealed low surface pH values (3.0 - 3.5) but pH values of 6 and higher at a depth of 2 ft. These samples and the absence of plant growth over the backfilled impoundments indicated that overland flow was a major route of migration for the acidic materials. Little penetration of acid with depth had occurred outside of the impoundment boundaries.

Analysis of soils within the backfilled impoundments showed high concentrations of sulfates, particularly in impoundment 2 (Fig. 3). Total sulfates reached 100,000 ppm both at and below the old impoundment bottoms. Soluble sulfates reached 98,000 ppm in the sludges buried in impoundment 2. The soluble sulfate level decreased with depth. Soluble sulfates, as a percent of total sulfates, ranges from 94% to 35% at 6 and 11 ft depths, respectively.

Total sulfate levels in impoundment 1 were between 26,200 and 14,000 ppm at 5 ft (at the old impoundment bottom) and 12 ft depths, respectively. These levels were many times higher than the soluble and total sulfate values found in the background sample (375 ppm and 1,700 ppm, respectively).
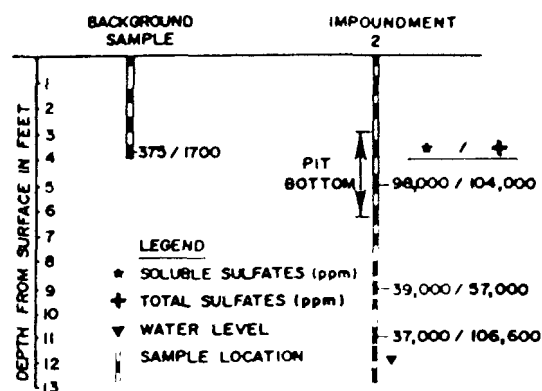
Figure 3
Soluble and Total Sulfates (ppm) for Background and Backfilled Impoundment

Values for toxic metals were slightly above background. Metals levels were, however, well within the range typically found in soils (Table 2). Spent acid and an EP extract of the impounded sludge revealed no metals above the maximum allowable concentration (Table 2). Chromium, with a EP toxicity value of 3.6 ppm in the spent acid, was the only metal of concern. Chromium values in the soil samples ranged from 12 to 33 ppm with a background value of 12 ppm. The iron concentration was considerably higher than the background sample but was within the range normally found in soils.

Table 2
Analysis of Samples, Maximum Metal Concentrations Allowed in EP Extract, and Typical Range in Soils*

Parameter	Spent Acid	Impounded Sludge	EP Extract of Sludge	Maximum Allowed in EP Extract	Background Soil	Backfilled Soil	Typical Range in Soils[4]
Soluble Sulfates	NA	9.8%	NA	NA	375	0.6%	---
Total Sulfates	7.3%	10.4%	NA	NA	1,700	1.5%	---
pH	<1	2.5-3.5	NA	NA	6.2	3.3	---
As	0.22	1.3	<0.01	5.0	<0.2	0.2	1-50
Cd	8.3	0.6	<0.02	1.0	<0.1	0.3	0.01-0.7
Cr	3.60	16.0	<0.20	5.0	12.0	12.0	1-1000
Fe	9.5%	12.3%	NA	NA	2.4%	14.9%	.7-55%
Pb	0.72	55.0	0.34	5.0	15.0	35.0	2-200

* All values given in parts per million unless otherwise indicated.

NA - Not Available

Groundwater leaving the site (downgradient) had elevated concentrations of sulfates and total dissolved solids (TDS). Values obtained for pH and chromium were similar for monitoring well water samples collected upgradient and downgradient (Table 3).

Table 3
Analysis of Groundwater Samples Taken During Site Assessment

Monitoring Well No.	Position of Well	pH	SO_4 = (mg/l)	TDS* (mg/l)	Cr (mg/l)
1	upgradient	6.1	90	550	≤ 0.02
2	downgradient	6.1	1800	3050	≤ 0.02
3	downgradient	6.1	2000	3150	≤ 0.02

* Total Dissolved Solids

CLOSURE OF BACKFILLED IMPOUNDMENTS

The assessment revealed that soil within and below the backfill had elevated sulfates and low pH values. These conditions extended to a depth of 12 ft over an area of 1.25 acres for a total volume of approximately 24,000 yd³ of affected soils and sludge. Attempting to remove this volume of material for treatment or off-site disposal would be extremely expensive. Consequently, it was decided to evaluate methods for in situ treatment.

The most promising method found for in situ treatment of acidic wastes was lime injection. Positive attributes of this method included low cost, availability and the fact that injection equipment could maneuver on the present backfill. Lime injection is primarily used for soil stabilization in areas with expansive clays.[5] The technique uses a hydraulic system to force perforated steel tubes into soil and a high pressure duplex mud pump to inject the slurry. For a horizontal spread of 2.5 to 3.5 ft, one injection sequence is necessary for each 25 ft² of area.

After it was decided that the appropriate closure technique for the backfilled impoundments was lime injection, the following five phases were delineated:

•Determination of the lime required to bring the backfilled material to a pH of 6.5
•Subsurface injection of lime (calcium hydroxide slurry) into the backfilled impoundments
•Surface application of calcium carbonate ($CaCO_3$) to the affected soil surfaces
•Revegetation of the area
•Continuation of groundwater monitoring

The closure plan involved injection of lime to a depth of 12 ft over 1.25 acres of backfill. The main objective of this step was to reduce movement of sulfates by reducing the sulfate concentration in the soil solution. Soil channels clogged with lime would reduce the rate at which migrating liquids would enter groundwater. In addition, the increased soil pH and calcium concentration in these channels would tend to decrease sulfate concentration in solution. The level of sulfates in groundwater should be substantially reduced over time. The exceptionally high sulfate levels in the soil, however, will prevent the sulfate concentration in downgradient water samples from returning to the background value of 375 mg/l.

Lime slurry was injected into the ground at a pressure of 50 to 200 lb/in.² Slurry initially flowed into the soil through open joints, fissures, fractures and other channels. These interconnected veins of lime served to both increase pH and decrease permeability. The slurry was made by blowing powdered calcium oxide (CaO) into a 16,000 gal tank. Two pounds of CaO were mixed with each gallon of water to form a calcium hydroxide [$Ca(OH)_2$] slurry.

Sulfates migrated to the groundwater through the same channels through which the slurry would flow. Consequently, lime injection would treat the zone considered most critical (i.e., the pores and ped faces associated with these channels).

The total lime requirement was calculated as follows:
•A sufficient number of soil cores were collected to be representative of the entire volume of backfill, sludge and subsoil to be treated.
•These cores were composited, and studies were conducted on the composited sample to determine the amount of CaO needed to bring the backfilled area to a pH of 6.5.

The total lime required to bring the entire volume of material to pH 6.5 was calculated to be 172 tons. The $Ca(OH)_2$ slurry was injected at 5 ft intervals, using a small tractor equipped with 12 ft injection rods mounted on the front (Fig. 4). The cost of this operation was $0.06/ft³ of soil, or approximately $32,000.
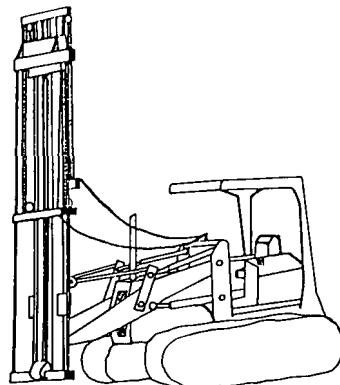
Figure 4
Tractor Equipped with Lime Injection Rods

Slurry was injected until refusal, the point at which the slurry broke through the surface. After one pass across the area, 86 tons of CaO had been injected, or one half of the lime requirement. Cores of soil were collected in the treated area 24 and 48 hr after injection to evaluate the effectiveness of the lime injection. These samples were taken between injection points. Free calcium slurry was visible in nearly all samples, and pH values ranged from 3.0 to 11. Two cores had pH values between 6.0 and 8.5 throughout. Samples taken 8 months after the injections, however, had pH values that were only slightly higher than before the injections and no free calcium was visible. As indicated in Figure 5, little change in pH can be expected until injection of more than 75% of the lime required for neutralization.

Sulfates in the groundwater decreased from 2,000 mg/l to about 950 mg/l, and TDS dropped slightly in both downgradient wells one month after treatment. Sulfate levels began to increase four months after the injections (Fig. 6). The initial decrease in sulfates was thought to be due to the small amount of lime that was injected directly into the groundwater. Long-term decrease of sulfates and TDS can be expected after the other half of the lime requirement is injected into the backfilled impoundments.

Liming of the surface soil with $CaCO_3$ and revegetation of the affected areas have already been completed. A combination of
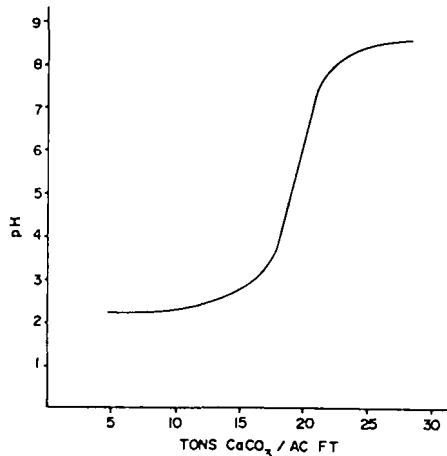
Figure 5
Titration Curve for Backfilled Soils
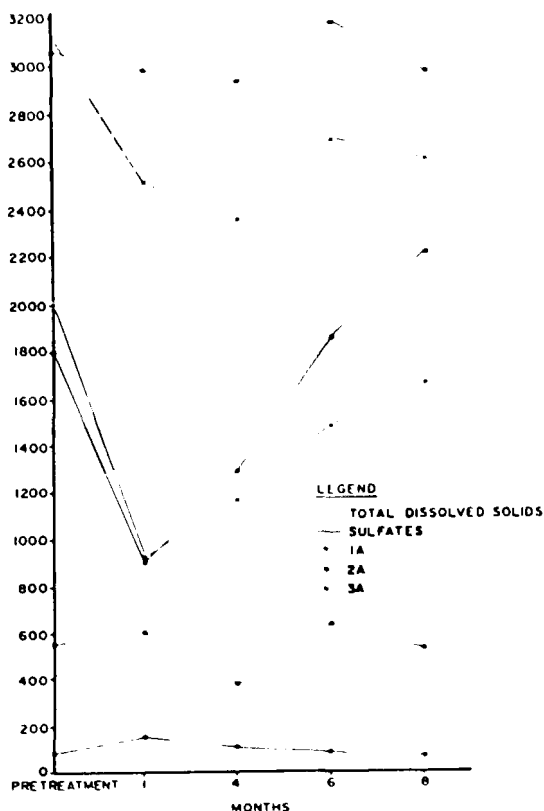
Figure 6
Total Dissolved Solids (TDS) and Sulfate Concentrations (ppm) in Groundwater Wells Near the Previously Backfilled Impoundments

ryegrass and bermuda grass was planted. Groundwater monitoring will continue for several years after the completion of lime injection.

ASSESSMENT OF THE ACTIVE IMPOUNDMENTS

Objectives of the active impoundment assessment were as follows:
• To determine the strength of the impounded acid
• To evaluate the effectiveness of various liming agents that could be used to neutralize the acids
Objective number one was met by collecting, compositing and neutralizing samples of the acidic water in impoundments 3 and 4. In a laboratory pilot study, between 14 and 17.5 g of calcium carbonate were required to neutralize one liter of the impounded acids.

Liming agents used in the laboratory study included lime kiln dust, fresh cement kiln dust, stockpiled cement kiln dust, waste cement from an oilfield drilling operation, calcium hydroxide and agricultural lime (CaCO₃) The lime kiln dust had good neutralization potential, but it could only be obtained in a dry powder which had to be blown across the impoundments. Due to unfavorable prevailing winds, blowing the lime kiln dust would cause an unacceptable air pollution problem.

After samples of the impounded water were neutralized, they were evaluated for both volume of resulting solids and quality of remaining liquids. Based on both criteria, calcium hydroxide was chosen. Use of calcium hydroxide resulted in formation of a relatively small quantity of suspended solids and a water quality high enough to be discharged into the city sewage system.

CLOSURE OF THE ACTIVE IMPOUNDMENTS

Closure of the active impoundments consisted of five phases:
• Neutralization of the liquid and pumping to the city
• Neutralization and dewatering of the sludges
• Investigation of the soils beneath the impoundments

• Placement of a cover in accordance with regulations to close impoundments as landfills
• Continuation of groundwater monitoring

Impoundment number 3 was treated first. A slurry tank was positioned next to the dike, and calcium hydroxide slurry was pumped into the impoundment. Two gas powered air compressors were used to aerate the impoundment and aid mixing. There was enough pressure from the slurry pump to keep the injection line on or near the surface of the liquid in the impoundment. The line moved around considerably; by relocating it to different sections of the impoundment after each tank of slurry, the lime slurry was injected in all areas of the impoundment. The resulting liquid had a pH of 6.7 and an iron content of <0.1 mg/l. By allowing for settling, the total suspended solids value was also low enough to permit the liquids to simply be pumped into the city sewage system.

Neutralization of impoundment number 4 did not go quite as smoothly. Because of a drainage ditch between impoundment 4 and the road, the slurry tank was parked approximately 225 ft from the impoundment. This distance resulted in a significant pressure drop in the injection line which then sank to the impoundment bottom. Consequently, more mixing action was required. After liquids in impoundment 4 were neutralized, they were discharged to the city sewage system.

Calcium slurry that was deposited on the impoundment bottom during the process of neutralizing the impounded liquids had pH values as high as 11. The original plan was to dewater these sludges by pushing in the impoundment sides with a bulldozer. However, this proved very difficult due to the volume and weight of the sludge. It was, therefore, necessary to pump most of the sludge into a diked drying bed for dewatering. Sludge in the drying beds was disced several times to aid drying. This process also mixed the sludge with the underlying soil. The pH values of the sludges after drying ranged from 6.3 to 8.3. This mixture contained 47% silt and about 6% clay. Once dry, the sludges were pushed back into the impoundment as fill.

Soil samples were taken across both impoundments (3 and 4) once they were backfilled with the neutralized sludge and soil. These samples showed basically a 4 ft zone of soils with pH values between 4.0 and 6.7. At 4 ft below the surface, the pH of the soils decreased to between 2.1 and 2.5. Low pH soils extended to a depth of 9 ft.

Calcium hydroxide [Ca(OH)₂] slurry injection was again chosen as the method of treatment for these buried soils. This time the entire lime requirement was injected. That is, 5 ft centers were used with a second pass beginning with injection points in the middle of four previous injection points. One hundred and eighteen tons of slurry were injected into this 5 ft thick zone (19.6 tons of CaO/acre foot; 34.9 tons of CaCO₃/acre foot). This procedure also left a 1 to 2 in. layer of calcium hydroxide on the soils, which was worked into the soil surface.

Three feet of compacted clay soil were placed over impoundments 3 and 4. The clay was then covered with 1 ft of topsoil, and the topsoil was planted with winter ryegrass and bermuda grass. Groundwater monitoring will continue until all values stabilize or return to background levels.

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ORGANIC SLUDGE STABILIZATION: AN OPTION THAT WORKS

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INTRODUCTION

Over the past 30 years, repositories for the residues of the manufacturing industry have accumulated to such an extent that there are more than 170,000 pits, ponds and lagoons containing industrial waste reported throughout the United States. The types of chemicals, qualities and their effects or potential effects on the environment are unknown. Two environmental laws have been passed which form the basis for addressing these situations—they are the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation and Liability Act. Operating within the framework of these laws, industry is developing approaches for securing some of these problem sites. One such approach is illustrated in the following case study.

Velsicol's Past Disposal Practices

As a result of the manufacture of resins and chlorinated organic chemicals over a period of approximately 30 years, Velsicol's Marshall, Illinois plant generated an 8.5 acre, 17-million gallon pond of organic waste. The 5/6 Pond, as it is referred to, once consisted of two ponds with an adjacent "bone yard" of old equipment, drums, pallets, etc., and covered a total area of approximately 22 acres. During the period from 1935 to 1966, almost all of the plant effluent containing wastes from the resin and chlordane units passed through these ponds, and the second phase materials were retained in the ponds as a sludge. Prior to the promulgation data of RCRA, the use of these ponds was terminated.

SOLIDIFICATION/STABILIZATION

In an effort to secure the site, Velsicol began an extensive program aimed at the stabilization of these residual sludges in 1980. This research project included the investigation of various solidification methods. It was hoped that these methods would become part of a total remedial measure program.

Because the classical approach to stabilization failed, attention was shifted to developing methods of bridging the materials so that a cap could be constructed over the sludge. Concurrent with the investigation of this second approach, evaluations of the sludge's potential for stabilization were sought from several consulting firms. The result—at least five proposals with varying degrees of effectiveness and with costs ranging from $.35 to $1.00/gal for materials and labor alone were received.

After becoming dissatisfied with bridging the sludge as an acceptable approach, Velsicol intensified its efforts at stabilization through an independent laboratory and developed a proprietary process for stabilization of the organic sludge. This process is unique for the following reasons:

- Solidification/Stabilization—The process is successful in the presence of sludges containing over 40%, by weight, of organics and allows the binding materials used to produce a permanent set in the mixture. The overall expansion of the stabilized mass is essentially nil.
- Construction Costs—The process allows for a minimum of construction equipment. No exotic mixers or other unusual equipment are required, and the sludge being stabilized in this instance does not need to be pumped out to a laydown pad for stabilization. The speed of the set is remarkable, and construction equipment can operate on the area within a short period of time. All these factors, including the cost of materials, have produced a cost/benefit ratio that is more competitive than other technologies proposed by outside firms.
- Health and Hygiene—The process allows use of a construction technique which minimizes handling as well as worker exposure. The technique uses in-place stabilization which dramatically reduces the vaporization of any volatile organics during the mixing activity.
- Leachate Generation—Application of this technology has resulted in improvements of the quality of leachate generated by passing through a column of the stabilized sludge. This improvement is especially significant with the less volatile chlorinated hydrocarbons.

Process Details

As developed, the process centers on the use of certain moderately reactive materials being mixed with sludge with high organic content. The materials initially absorb the organics, including the oils and resin in the sludge, rendering the sludge a granular, clay-like material. A setting reaction takes place, and the stabilized sludge stiffens but remains very workable. These resulting materials have a permeability of 7×10^{-6} to 3×10^{-7} cm/sec, a California Bearing ratio of 10-14 and an expansion ratio of less than 1:1.1. Other characteristics include a wet density of 91.3-132.9 lb/ft^3 and a dry density of 60.0-109.2 lb/ft^3.

Because the 5/6 Pond is non-homogeneous, it, like many others, does not have consistent physical or chemical characteristics throughout. The pond's stratified layers are rich in oils, both organic and inorganic, solids and emulsions. Due to this inconsistency, the preparation of custom formulas for various sections of the pond have been required, and based on the physical character-

istics of the sludge, field modifications to the laboratory-derived formula have been successfully made during the stabilization process. In order to assure effective treatment, the final physical properties after curing are determined on a random test basis.

The application is accomplished by using standard earthmoving equipment and allows for mixing in place to a depth of 10 ft. The 5/6 Pond was originally divided into four sections by earthen levees; these levees were used as the initial working platform. The mixing of the additives with the sludge takes place by course on the periphery of the pond and the dividing levees using standard earthmoving equipment. Since the stabilized sludge sets within three days and is able to withstand heavy equipment traffic at the time, an extended work platform is formed.

Closure

Once stabilized, the 5/6 Pond will be capped. The proposed cover system differs from the capping of a typical landfill. One of the major differences is that most municipal refuse is compacted in cells, and these can be built up to more closely match the desired final contour. In the case of the 5/6 Pond, the residue to be capped is a fluid sludge lying in a nearly level plane.

In order to create the desired slope, the solidified material is shaped to the appropriate slope prior to the placement of the compacted clay cap. The fact that the stabilized material can be shaped is a very important attribute. This characteristic allows the cap to be of uniform thickness and will minimize the use of expensive clay. The cap will consist of three basic layers. The first layer will consist of 3 ft of compacted clay and will serve as a barrier to the penetration of water. The second layer will be made up of 0.5 ft of gravely sand to serve as a drainage layer. To prevent washout at the toe of the drainage layer, typar and rip-rap will be used to stabilize these areas.

For protection against erosion, the third layer will be 0.5 ft of top soil cover to support vegetation. To convey surface water in a sheet flow pattern away from the site, the final cover will be contoured. The quality of the stormwater run-off from the cap will allow it to be discharged to the small creek adjacent to Velsicol's plant site.

The proposed monitoring system for the site will consist of eight wells to be used to monitor groundwater in the drift as well as the bedrock. Six downgradient wells will be placed in three locations on the westerly side of the site. Two wells will be placed in one location upgradient on the easterly side.

CONCLUSIONS

A permit for stabilizing the pond sludges at the Marshall site was approved by the Illinois Environmental Protection Agency, and on-site inspections have been conducted during implementation by both the State and the USEPA which was apprised of the process at the beginning. Additionally, specialists in hazardous waste handling from the National Enforcement Investigations Center visited the site and reviewed the process.

This stabilization process is, of course, only one part of an overall remedial program undertaken by Velsicol. Although the process does not result in the conversion of waste from hazardous to non-hazardous, it is an effective demobilization technique.

In pursuit of Velsicol's goal to secure the 5/6 Pond, the overall knowledge gained by the company has produced a process which lends itself to the economical solution of similar sludge ponds having a broad range of composition. Velsicol's stabilization technology is cost-effective—for the Marshall 5/6 Pond project, less than $.30/gal—and results in 75% improvement in leachate quality with respect to volatile organics, shows little measureable expansion in volume as opposed to 50-100% for several other processes and produces workable material capable of being readily relocated or put into an on-site disposal system. Based upon the evaluation of samples from several other sites, it has been determined that a wide variety of industrial organic sludges can be stabilized using this technology.

IN SITU VITRIFICATION—A POTENTIAL REMEDIAL ACTION TECHNIQUE FOR HAZARDOUS WASTES

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INTRODUCTION

In situ vitrification (ISV) is an innovative technology being developed as a potential method for stabilizing transuranic (TRU) contaminated wastes in place. Although the process is being developed for TRU contaminated wastes, it is envisioned that the process could also be applied to hazardous chemical wastes.

In situ vitrification (ISV) is the conversion of contaminated soil into a durable glass and crystalline wastes form through melting by joule heating. The technology for in situ vitrification is based upon electric melter technology developed at the Pacific Northwest Laboratory (PNL) for the immobilization of high-level nuclear waste.[1] In situ vitrification was initially tested by researchers at PNL in August, 1980 (U.S. Patent 4,376,598).[2] Since then, ISV has grown from a concept to an emerging technology through a series of 21 engineering-scale (laboratory) tests and 7 pilot-scale (field) tests. A large-scale system is currently being fabricated for testing. The program has been sponsored by the U.S. Department of Energy's (DOE) Richland Operations Office for potential application to Hanford TRU contaminated soil sites.

The ISV development program is utilizing three sizes of vitrification systems. The distinguishing characteristics of each system are power level, electrode spacing and mass of block produced, as shown below:

System	Power (kW)	Electrode Spacing (m)	Vitrified Mass Per Setting (t)
Engineering	30	.023-0.36	0.05-1.0
Pilot	500	1.2	10
Large	3750	3.5-5.5	400-800

Major advantages of in situ vitrification as a means of stabilizing radioactive waste are:
- Safety in terms of minimizing worker and public exposure
- Long term durability of the waste form
- Cost effectiveness
- Applicability to different kinds of soils

PROCESS DESCRIPTION

In situ vitrification is a process for stabilizing and immobilizing contaminated soils. To begin the process, shown in Figure 1, graphite electrodes are inserted vertically into the ground in a square array. Graphite is placed on the surface of the soil between the electrodes to form a conductive path. and an electrical current is passed between the electrodes, creating temperatures high enough to melt the soil. The molten zone grows downward, encompassing the contaminated soil and producing a vitreous mass. Convective currents distribute the contaminants uniformly within the melt. During the process, gaseous effluents emitted from the molten mass are collected by a hood over the area and routed through a line to an off-gas treatment system. When power to the system is turned off, the molten volume begins to cool. The product is a block of glass-like material resembling natural obsidian. Any subsidence can be covered with uncontaminated backfill to the original grade level.
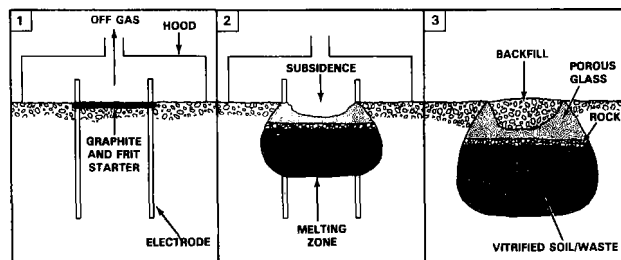
Figure 1
In Situ Vitrification Process Sequence

The principle of operation is joule heating, which occurs when an electrical current passes through the molten medium. As this molten mass grows, resistance decreases; to maintain the power level high enough to continue melting the soil, the current must be increased. This is accomplished by a transformer equipped with multiple voltage taps. The multiple taps allow more efficient use of the power system by maintaining the power factor (the relationship between current and voltage) near maximum. The process continues until the appropriate depth is reached. Melt depth is limited as the heat losses from the melt approach the energy deliverable to the molten soil by the electrodes.

To contain off-gases that are released from the melting process, an off-gas hood that is operated under a slight vacuum covers the vitrification zone. The hood also provides support for the electrodes. The off-gases are routed from the hood to a treatment system which scrubs and filters hazardous components.

A more detailed description outlining the power system design and the off-gas treatment system follows.

Power System Design

The power system design is similar for all three scales of the ISV program. A transformer connection converts three-phase alternating current electrical power to two single-phase loads. The single-phase loads are connected to two of the electrodes, which are arranged in a square pattern, creating a balanced electrical load on the secondary. The even distribution of current within the molten soil produces a vitrified product almost square in shape to minimize overlap among adjacent settings. Multiple voltage taps and a balanced load allow a near constant power operation which shortens run time and thus minimizes cost.

Off-Gas Treatment System

In both the pilot- and large-scale systems, the hood collects the off-gas, provides a chamber for the combustion of released pyrolyzed organics and supports the four electrodes embedded in the soil. Much of the heat generated during the ISV process is released to the off-gas stream. This heat is removed in the off-gas treatment system, so that the temperature of the gas which exits after treatment is close to ambient.

There are three major kinds of treatment for the off-gas system (Fig. 2). First, the gases are scrubbed in two stages with a quencher and tandem nozzle scrubber. These scrubbers remove particles

down through the submicron range. Second, the water in the saturated gas stream is removed by a vane separator and condensor followed by another vane separator. Third, the off-gas is heated, insuring an unsaturated gas stream at a temperature well above the dewpoint, and then it is filtered with two banks of high efficiency particulate air (HEPA) filters. Both the pilot- and large-scale systems are trailer mounted and therefore mobile.
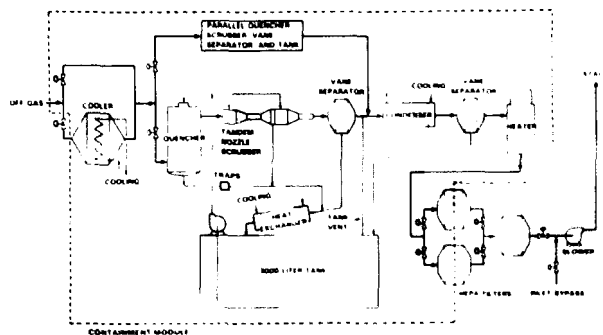
Figure 2
Schematic for the Large-Scale Off-Gas System

The off-gas treatment system required for ISV application to hazardous chemical wastes will probably be simpler than that required for radioactive application. Specifically, the requirements for dewatering and filtering the gas stream would probably not be necessary. In some special applications, where one of the contaminants becomes a toxic gas, it may be necessary to add a special treatment stage such as a charcoal bed.

PERFORMANCE ANALYSIS

The ability of the waste form to retain the encapsulated or incorporated radionuclides (some with very long half-lives) is of prime importance to the usefulness of the ISV process.

Vitrified soil blocks have been analyzed to determine their chemical durabilities with a series of tests including 24-hr soxhlet leach tests. The soxhlet leach rate for all elements was less than $1 \times 10^{-5} g/cm^2/day$, an acceptable value. These rates were comparable to those of Pyrex® or granite and much less than those of marble or bottle glass (Fig. 3).

A 28-day Materials Characterization Center test (MCC-1)[3] was also conducted on a contaminated soil sample that had been vitrified in the laboratory at 1600 °C. The overall leach rate of the vitrified soil is comparable to the PNL 76-68 waste glass developed for high-level nuclear wastes.[4] The measured release rate of Pu from the vitrified soil was $2 \times 10^{-7} g/cm^2/day$. Higher vitrification temperatures like those experienced in the field (~1700 to 2000 °C) are expected to lower the Pu leach rate.

SOXHLET CORROSION RATE, g/cm²-d x 10⁸
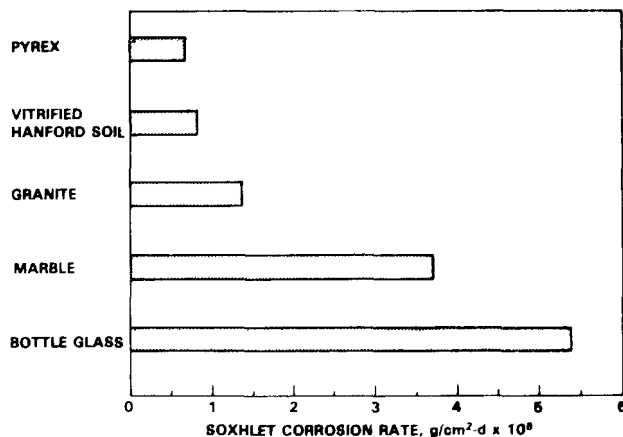
* Pyrex is a registered trademark of Corning Glass Works, Corning, NY.

Figure 3
Leach Resistances of Selected Materials

Another indication of the durability of the ISV waste form is found in a study of the weathering of obsidian, a glass-like material physically and chemically similar to the ISV waste form.[5] In the natural environment, obsidian has a hydration rate constant of 1 to 20 μm^2/1000 yr.[6] A value of 10μm^2/1000 yr, assuming a linear hydration rate, yields a conservative estimate of a 1 mm hydrated depth for the ISV waste form over a 10,000 yr time span. Since hydration is also the initial mechanism of weathering, the ISV block is expected to maintain its integrity at least through this 10,000 yr time period.

Another important factor to consider in the waste form evaluation is the migration of the radionuclides once they are a part of the molten waste form. In the pilot-scale field tests, the radionuclides did not move beyond the vitrified block. Furthermore, analysis of the blocks from the tests revealed that the radionuclides did not concentrate in the block but, instead, were uniformly distributed. These factors are very important considerations for application of ISV to chemical wastes containing toxic or heavy metals.

Far term (10,000 yr) performance assessments have been made to determine the effectiveness of selective vitrication for immobilizing high TRU concentration zones at a reference waste site at Hanford. Scenarios evaluated included inadvertent and intentional human intrusion, transients and permanent residents in the vicinity of the waste site. For these scenarios, the vitrified zone was covered by an engineered barrier, and this combination was compared to sites with no remedial action and sites with just an engineered barrier.

Results of the analysis showed that the amount of radioactive material available for human ingestion was reduced by up to 10⁷ for the site that was selectively vitrified and had engineered barriers. It was concluded that vitrification cannot prevent human intrusion into old or abandoned waste sites, but it can moderate its consequences. The groundwater pathway was not considered for this analysis because of the characteristics of the Hanford site. Insight into the long-term performance, when the groundwater pathway may be significant, can be obtained from the leach data presented in the preceding paragraphs.

Specific data on the leach rate of heavy metals are beyond the current scope of the ISV program; however, the data for radioactive contaminated soils indicate the potential for using ISV to isolate toxic and heavy metals from the biosphere.

The release of elements from the soil to the off-gas stream during processing was also studied. This partitioning is usually described as the decontamination factor. The higher the decontamination factor (the mass of an element in the soil divided by the mass released to the off-gas treatment system), the smaller the amount of an element that is released from the soil during processing.

Based on results from the pilot-scale system, it is estimated that for the large-scale system, soil-to-off-gas-hood DFs for less volatile elements such as Pu, Sr and U will be 1×10^3 to 1×10^4. More volatile elements such as Cs, Co and Te should have DFs of about 1×10^2. Low boiling heavy metals such as Pb and Cd should have DFs about 10. (Additional data on heavy metals presented later in the paper.)

Element retention increases with depth of burial and the presence of a cold cap and decreases with the presence of gas generating materials. Decontamination factors the off-gas treatment system (hood to stack) are as follows: for the semivolatiles (Cs, Co and Te), 1×10^4 and for the less volatile nuclides Sr and Pu, 1×10^5. Therefore, the soil-to-stack DFs are 1×10^6 for the semivolatiles and 1×10^8 to 1×10^9 for less volatile materials. For particulates, the DFs are about 1×10^{11}.

PROCESS PARAMETERS

PNL staff studied nine soils from waste sites all over the United States to determine how varying soil properties affect the vitrification process. None of the normal variations in properties such as electrical and thermal conductivities, fusion temperature, viscosity and chemical composition significantly impact ISV operation. While soil moisture increases the power requirements and run time of the ISV process, it is not a barrier to its use, having only a small

effect on the attainable melt depth. Soil moisture is an economic penalty proportional to the amount of heat required to evaporate the water.

The effect of materials buried with the waste itself, particularly those that are commonly found in waste sites, has been considered. These materials include metals, cements and ceramics, combustibles and sealed containers. While there are some limitations to the ISV process due to waste inclusions, they are not significant. The most significant consideration is sealed containers housing highly combustible organics. A large number of such containers could potentially increase the flow rate requirements of the off-gas system.

The processing capabilities of the large-scale ISV system are depicted in Figure 4. The width per setting ranges from 3.5 to 5.5 m, with attainable depths of 10 to 13 m. The depths are calculated on a conservative basis using nominally high heat losses. Metals can occupy 70% of the linear distance between electrodes with only a 10% decrease in voltage. This value represents process testing to date rather than the limit for the system. The void volume of 4.3 m³ and combustible packages of 0.9 m³ reflect the capacity of the off-gas treatment system. The solid combustible concentration of 3,200 kg/m/setting represents a situation that might be encountered in a typical landfill disposal operation. The combustible liquid concentration of 4,800 kg/m/setting again reflects the capacity of the off-gas treatment system. There is a design factor of two associated with all of the void volume and combustible loading numbers. The design factor will be verified by field testing the large-scale system in FY 1985.
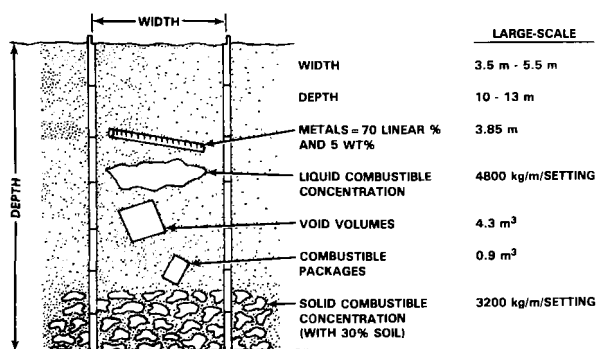
Figure 4
Large-Scale ISV System Capabilities

ECONOMIC ANALYSIS

The cost of using ISV as an in-place stabilization technique has been estimated by Oma et al.[7] The cost estimate includes expenses from the following four categories: site preparation activities, annual equipment charges, operational costs (labor) and consumable supplies such as electrical power and molybdenum electrodes. Five different configurations were evaluated including variations in operating manpower levels, power source costs and heat loss assumptions used by the mathematical model to predict processing efficiency. The cost comparison for vitrifying to a depth of 5 m for a reference contaminated zone configuration is given in Table 1. The process efficiency for vitrifying to a greater depth and a different contaminated zone configuration is lower.

Cost of electrical power and the amount of soil moisture in the area being vitrified can affect the economics of the process significantly. The influence of these two parameters on cost is shown in Figure 5. At low electrical rates (i.e., $0.029/kWh), power costs account for only 20% of the total operational cost. However, at $0.049 kWh and $0.0825 kWh, power costs account for 30% and 40% of the total cost, respectively. The energy cost has a ceiling at $0.0825/kWh; above this electrical rate, a portable generator can be leased and operated at an equivalent electrical rate of $0.0825 kHw.[2] Soil moisture increases the operating cost of the process by requiring more energy to vitrify a given volume of contaminated

soil because the water in the soil must be evaporated. This adds to the electrical energy costs and the time required to complete the process which, in turn, increases the cost contribution from labor.

Table 1
Cost Estimates for Five ISV Large-Scale Configurations

Number	Site	Power	Heat Loss	Manpower Level	Total Cost of Soil Vitrified, 1982 $/m³	Total Cost of Soil Vitrified, 1982 $/ft³
1	Hanford	Local	High	Average	187	5.30
2	Hanford	Local	Average	Average	161	4.60
3	Hanford	Local	Average	Above Avg.	183	5.20
4	Generic	Local	Average	Average	180	5.10
5	Generic	Portable	Average	Average	224	6.30

EXPERIENCE WITH HAZARDOUS/ORGANIC MATERIALS

During process evaluation with the 21 engineering- and seven pilot-scale tests, various hazardous, simulated hazardous and organic materials have been added to the test area to determine system performance. Some of these materials are Co, Mo, Sr, Cd, Cs, Pb, Ce, La, Te and Nd as nitrates; chlorides and oxides; organic solvents such as carbon tetrachloride, tributyl phosphate and dichlorobenzene; and combustibles such as cotton and rubber gloves, wood chips and paper. The three main conclusions drawn from these tests are: (1) burial depth attenuates release (e.g., 1 to 1½ m of uncontaminated overburden lowers release fractions significantly); (2) gaseous releases associated with combustibles result in a significantly higher release fraction; and (3) organics are pyrolyzed, resulting in combustion in the hood directly above the molten zone.

The importance of burial depth during pilot- and engineering-scale testing is illustrated in Figures 6 and 7, respectively.

Gaseous releases enhance the release fraction. Once the material is vitrified and incorporated into the vitreous mass, it is not available for further release except in direct proportion to its vapor pressure and in inverse proportion to its solubility in molten glass. However, gaseous release, which is usually associated with combustion, provides an additional release mechanism—entrainment—for those contaminants associated with the combustibles. This phenomenon can be seen by comparing Figure 7 with Figure 8 with respect to Pb and Cd. In these experiments, the process temperature was 1700 to 2000°C; thus, for low boiling, insoluble heavy metals, the release fraction can be up to several percent compared to semi- and non-volatile elements. Again, the release frac-
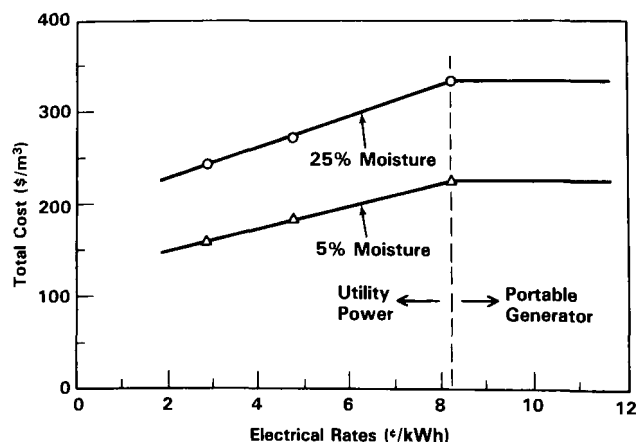
Figure 5
Cost of In Situ Vitrification as Functions of Electrical Rates and Soil Moisture

tion will be dependent upon the vapor pressure and the solubility in the glass.

Combustibles testing has included up to 50 kg of solid combustibles and 23 kg of tributylphosphate in a single experiment. Chromatographic, sample bomb and mass spectrometric analyses of the effluent from both the hood and stack indicate less than 5×10^{-3} volume percent release for light hydrocarbon, indicating nearly complete pyrolysis and combustion.

CONCLUSIONS

The following conclusions can be drawn from the evaluation of ISV technology:

Figure 6
Element Retention versus Burial Depth During Pilot Scale Tests

Figure 7
Element Retention versus Burial Depth During Engineering Scale Tests

- In situ vitrification is a developing technology that may have significant potential for selected hazardous waste disposal.
- Organic compounds are pyrolyzed during ISV. Subsequent combustion and off-gas treatment hold potential for permanent disposal of selected toxic organic wastes.
- Process economics for contaminated soil sites at Hanford are in the range of \$142 to \$230/m³ (\$4 to \$6.50/ft³) of soil vitrified. Differences in site geometry, electrical power costs, soil moisture and other factors can influence these costs. For a soil moisture 25%, and using a portable power supply, costs would be about \$320/m³ (\$9/ft³) of soil vitrified.
- Long-term (10,000-yr) performance analysis for TRU contaminants leads to the belief that ISV may minimize the effects of persistent toxic and/or heavy metal wastes.

When viewing the potential for ISV technology transfer from the nuclear to the hazardous waste arena, it is prudent to remember that ISV appears to be an excellent specific remedial action technique—it is not a panacea but, judiciously applied, the process holds promise to mitigate the effects of unprocessed buried chemically hazardous wastes.

Figure 8
Cd and Pb Release as a Function of Run Time

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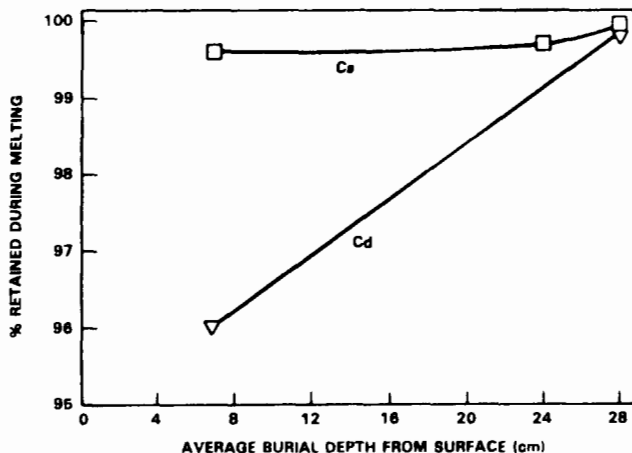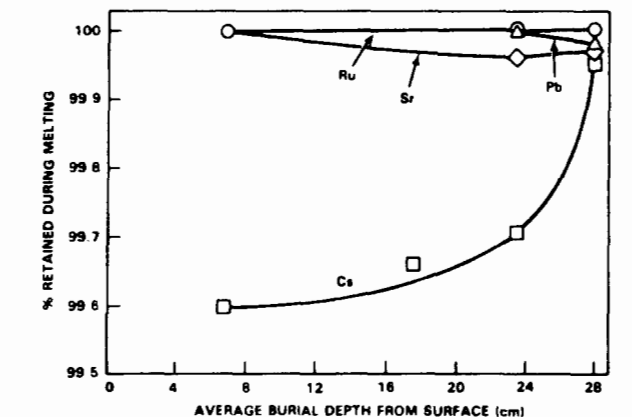
TREATMENT, SOLIDIFICATION AND ULTIMATE DISPOSAL OF HAZARDOUS WASTE STREAMS IN SALT FORMATIONS

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INTRODUCTION

In the mid-50s, the scientific community began to recognize the unique characteristics of rock salt as a potential host medium for the disposal of hazardous waste. In 1956, the National Research Council Committee of the National Academy of Sciences recommended that salt be investigated as a geologic medium for the long-term retention of liquid high-level radioactive waste.[1] These early requirements for the examination of the feasibility of storing high-level radioactive waste in salt led to the famed "Project Salt Vault" experiment initiated in 1965 by the Oak Ridge National Laboratory.[2] The objective of the study was to confirm the feasibility of disposal of high-level radioactive waste in salt by determining if there was a change in the stability of salt under the influence of extreme heat and radiation.

Spent nuclear fuel rods were emplaced in the Carey salt mine in Lyons, Kansas at a depth of about 1000 ft. For two years, the salt was exposed to radiation approaching 8×10^8 rad and temperatures reaching 390 °F. The conclusion of the experiment was that there were no adverse effects on the salt formation—the bedded salt structure had absorbed the intense heat and radiation without any measurable deformation.

A more exciting experiment in salt occurred in 1965 when the Atomic Energy Commission and the Department of Defense exploded a 5 kiloton nuclear device in the Tatum salt dome in southern Mississippi. The salt absorbed the heat, blast and radiation effects of the detonation without breaching. The only fractures found in the salt were near the point of detonation and they were only a few feet in length.[3]

These early experiments involving radioactive waste generated scientific interest in salt as a retention medium for non-radioactive hazardous waste. In 1975, the USEPA conducted a study of the feasibility of utilizing mined openings for disposal of non-radioactive hazardous waste.[4] One geologic medium studied was rock salt. The study conclusions showed that salt was one of the most desirable geologic hosts for hazardous waste retention due to its unique physical characteristics.

Currently, there are two hazardous waste disposal companies applying for USEPA permits to construct and operate non-radioactive hazardous waste disposal facilities in domal salt. One is in the state of Texas atop the Boling salt dome near Houston, the other is in Louisiana on the Vinton salt dome near the town of the same name.

SALT CHARACTERISTICS

Although a mineral, halite or salt is unlike other minerals in its physical characteristics. Foremost, it becomes plastic when sub-jected to extreme temperatures, generally above 390 °F. When a pressure exceeding 12,000 psi is exerted on the mass, it becomes viscous. However, these physical changes work to the benefit of containment. At lesser temperatures and pressures, salt still tends to move and this movement is referred to as creep. As a result, a salt mass can be fractured and, in time, it will close the fracture along the fracture plane. In other words, it is self-healing. This characteristic makes salt ideal as a retention vessel for hazardous waste. Compare this characteristic to hard rock such as granite. When hard rock is fractured, it remains so and thus creates an avenue for migrating fluids.

Salt's lack of permeability is also attractive for retention of hazardous waste; a permeability so low that it is considered impermeable. Because it will not permit the passage of fluids, from within or from outside the mass, it assures there will be no hydrological movement.

Strength is another positive characteristic. Salt averages 3000 psi compressive strength which is equal to most construction concretes in industrial use today.

As a result, you have a deeply deposited geologic medium that is self-healing, is strong and will not permit the migration of fluids. It is not surprising that the Federal Government is engaged in the study and design of repositories for high-level radioactive waste in salt.

SALT DEPOSITS

As illustrated in the accompanying map (Fig. 1), salt is found throughout the United States in either bedded formations or in massive salt domes.

Bedded salt resulting from deposition of past ocean incursions is the most common. The largest and thickest beds of salt are found in the Salina basin encompassing the states of Michigan, Ohio, New York, Pennsylvania and West Virginia. Beds of salt can be found in Michigan, for instance, that are 1,800 ft thick. Further west, underlying the states of Montana, North and South Dakota, are salt deposits known as the Devonian salt basin. The Cimarron and Permian salt basins are found stretching from Kansas through Oklahoma down into Texas and New Mexico. Then there are the Paradox and Supai basins in the far west.

Of the occurrences of salt, however, salt domes are the most unique. Over 500 massive pillars of salt occur in the Gulf Coast Embayment. About half are offshore stretching from southwestern Alabama down to the tip of Texas. They also extend further into Mexico. These are huge masses of salt with diameters up to 10 miles and depths exceeding 50,000 ft. It is postulated that these domes of salt were created from pressures exerted on the mother salt laid
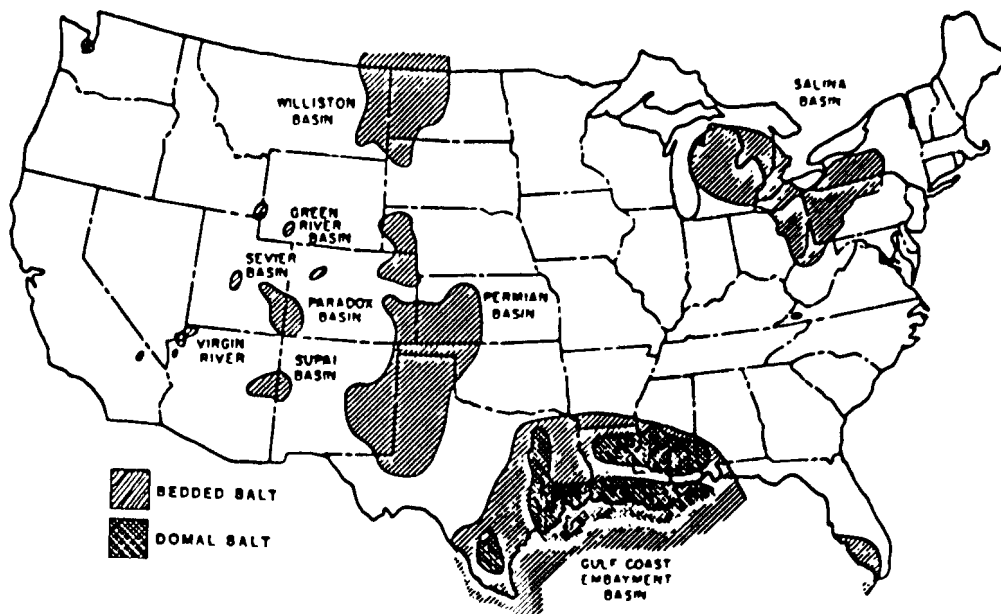
Figure 1
Salt Formations in the United States

down in huge quantities during the incursion of the Gulf of Mexico which flooded most of the south and southwest in past geologic time. As shown in Figure 2, these upward movements of salt resemble what might take place if one were to quickly push downward a hand in a pan of bread dough. Just as the dough would squeeze upward through one's fingers, the salt has moved upward due to the imposed pressure.

Salt domes have been the source of oil and gas exploration for many years. In fact, the first oil gusher in Texas was discovered on the periphery of the famed Spindletop salt dome in Beaumont. Because of the upward thrusting of the salt, geologic strata in the adjacent area are forced upward as well, creating pockets of entrapment surrounding the dome (Fig. 3). As a result of the heavy concentration of oil and gas exploration around salt domes, much is known of their character, size and consistency.

CREATING VOIDS IN THE SALT

There are two methods of creating a void in the salt to serve as a retention vessel for hazardous waste. The first, and most common, is physically mining the salt as is done in a coal mine. However, this procedure is labor intensive and expensive in comparison with the other method called solution mining. In solution mining, as the term infers, one injects water into the salt mass, salt dissolves and the resultant brine is extracted thus creating a void. In actual practice, it is much more complicated. The following is a description of

how a void—referred to as a salt cavern—is constructed by solution mining.

A well is drilled into the salt formation to the prescribed depth. Once the well is cemented into the strata and salt, two suspended casings are hung in the open well, one inside the other (Fig. 4). Fresh water is then injected into the inner handing casing and the resultant brine is withdrawn through the annulus between the two casings. This process continues until a sump has been created in the salt cavern that will eventually hold insolubles that are found in the salt. The insoluble particles, mostly anhydrite, fall to the bottom of the cavern by gravity and remain there throughout the developmental process.

Once a sump has been created of sufficient size to contain the total insolubles to be released during creation of the entire cavern, the hanging casings are moved to another position to further expand the walls of the new cavern. At a certain stage, the flow of fluids is reversed with the fresh water being injected through the an-
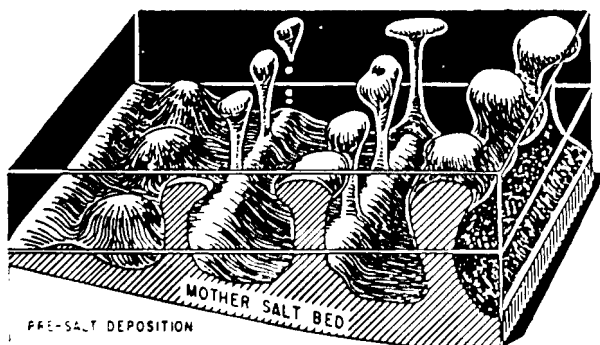
Figure 2
Schematic Diagram of Salt Pillar Formations
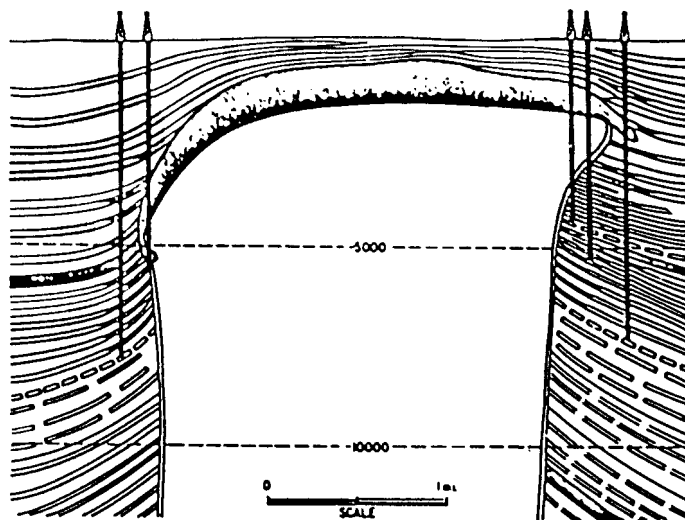
Figure 3
Barbers Hill Dome, Mont Belview, Texas

nulus and the brine withdrawn up the inner casing. This process is repeated until the cavern has reached the designed configuration.

If the cavern is to be created in bedded salt, it will be horizontal in shape due to the horizontal planing of the salt beds. Conversely, if the cavern is constructed in domal salt, the vessel will be long and tubular due to the available depth of the salt. Once the cavern is created, it is then voided of fluids and prepared for hazardous waste disposal.

THE DISPOSAL PROCESS

In the family of inorganic wastes, there are basically seven categories of chemically compatible waste. With the exception of lithium and fluorides in heavy concentration, none of these groups of waste react chemically with sodium chloride. As a result, they can be exposed to the salt surfaces of the newly created cavern without causing any undesirable chemical reaction.

As the inorganic wastes are received at the site, they are batched into chemically compatible groupings and held on the surface until sufficient quantities are on hand for processing.

During the treatment process, the waste stream is dewatered if it is too aqueous and the resultant moisture is retained for future use in the slurry system to be described later. If the waste is acid, it is neutralized using a base, hopefully utilizing another waste that is basic. With the exception of neutralization and dewatering, very little has to be done in the treatment phase to make the waste stream ready for solidification.

When sufficient volume of a particular group of waste warrants processing and movement into a cavern, the disposal process is initiated. First, the moisture content is determined and the fluid is moved via pipeline to an automatic batch facility where a solidification compound is added. Once the chemicals are mixed, the mass becomes a slurry, is pumped to the wellhead over the cavern and moves by gravity and minimal pressure to the interior of the cavern.

The slurried mass must fall distances exceeding 2,000 to 3,000 ft. As a result, there must be controls to prevent particulate separation during the fall. These controls are manifested in finite measurements of the total fall distance and manipulation of the casing.

As the slurry reaches the solidified layer of waste at the bottom of the cavern that preceded the batch being pumped, it will tend to seek uniform layering and will fill any crevices or rough edges found in the salt wall. After the prescribed length of time, the mass will harden to a compressive strength averaging 3,000 psi which is equal to the compressive strength of most salt formations.

The time element involved in pumping batches into the same cavern is in direct relation to the hardening time consumed by the preceding batch. In some cases, curing time will be as quick as 6 hr, in others the time will be held to 48 hr due to the slurry consistency.

When the cavern is almost filled, the remaining void will be used as an anchor for the plug that will be created in the borehole (Fig. 5). The borehole, with the cemented casing remaining, will be pumped full of cement from the top of the waste to within 10 ft of the surface. Once the cement plug hardens and is tested for total curing, the wellhead will be removed and 10 feet of soil will be emplaced over the cement plug. At this point, the cavern cycle is complete and the surface can be returned to its original use.

Such a facility constructed over domal salt would consume a mere 20 acres of land yet would be capable of disposing of an estimated 25,000,000 gal/yr for 20 years. If the same surface facility were constructed over bedded salt, the caverns would be smaller and the total land requirement would increase proportionately.

In comparison with a landfill, one acre of salt disposal on the surface equates to five acres of landfill 30 ft deep. Using the 5:1 ratio, it is obvious that land utilization is greatly enhanced by the salt cavern alternative. In addition, the land can be returned to its original use when the salt repository is filled; that is not true for a landfill.

COMPARISON OF ALTERNATIVES

There are no limitations if one uses the salt disposal technology (Table 1). Salt will accept PCBs, dioxin, heavy metals and
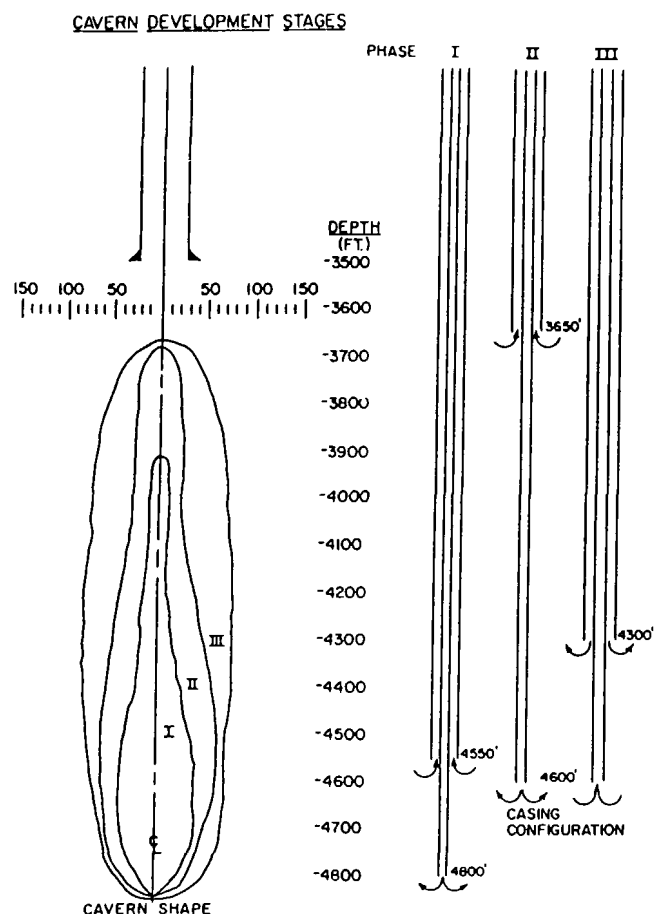
Figure 4
Solution Mining to Form a Salt Cavern
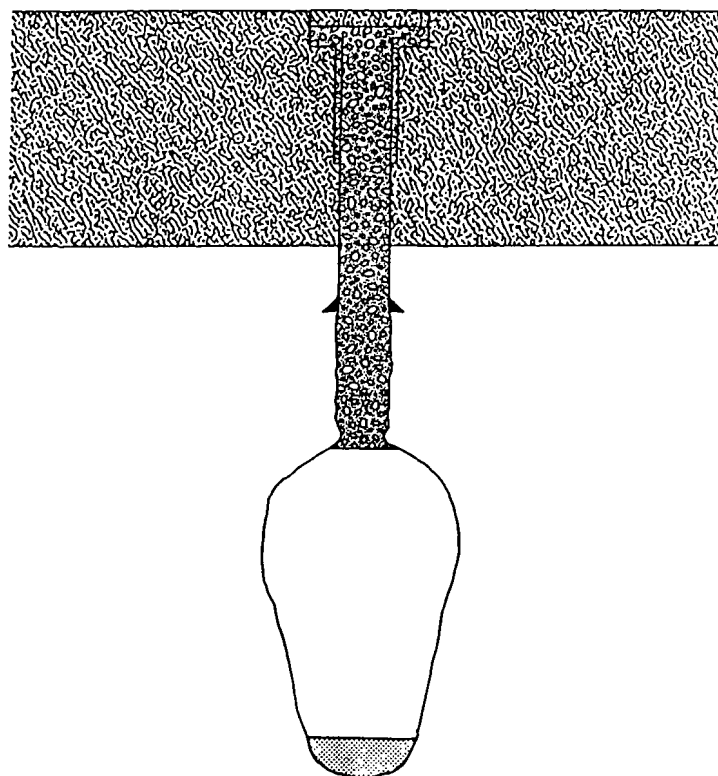
Figure 5
Filling of a Salt Cavern and Subsequent Closure

poisons—many of which cannot be landfilled, incinerated, chemically processed, recycled or injected into a deep well disposal system.

Table 1
Hazardous Waste Disposal Option Limitations

	PCB	Dioxin	Heavy Metals	Poisons
Landfill	No	No	No	No
Incineration	Yes	No	No	No
Chemical Processing	No	No	Yes	Yes
Deep Well Injection	No	No	No	No
Salt Disposal	Yes	Yes	Yes	Yes

From a cost standpoint (Table 2), the salt disposal system cannot compete with deep well injection which is a relatively cheap alternative. However, there are some characteristics associated with deep well injection that minimize its use in certain instances. For example, if the fluid to be injected into a deep well contains suspended solids 5 microns or more in size, the chances of successful injection are diminished considerably due to the plugging of the injection strata. Also, there is growing public and political concern over deep well injection as a continued alternative because of the possibilities of fresh water aquifer contamination.

Table 2
Cost of Hazardous Waste Disposal Options

Method of Disposal	Cost ($/gal)
Landfill	$0.20 - $1.50
Incineration	1.50 - 8.00
Chemical Processing	3.00 -15.00
Deep Well Injection	0.15 - 0.50
Salt Disposal	$0.50 - $3.50

The salt technology compares more favorably with the landfill alternative in cost. However, it is capable of handling a larger variety of waste streams due to USEPA limitations on substances banned from being placed in a landfill.

Salt would provide a natural repository for residue created during incineration. And, it would serve ideally as a system to support chemical processing residue.

"Disposal in salt is a technically attractive alternative,"[3] stated Ronald D. Hill, Director of Solid and Hazardous Wasted Research Division of USEPA's Cincinati group. Hill further stated that the concept is technically and economically feasible and encouraged the author to continue research to bring the technology to the industrial sector.

Dr. Joel S. Hirschhorn of the Office of Technology Assessment for Congress stated the technology was "...several orders of magnitude better than anything on the horizon" when he was briefed on the concept.[4]

USEPA Region VI, which controls the states having most of the salt domes in the Southwest, is supportive of the technology for salt dome disposal as another alternative. Many of the regulatory agencies of states that have native salt are also supportive.

DOUBTS AND PERCEPTIONS

When presented to the lay person, this concept envokes enthusiastic support, but there are those that challenge its viability with respect to either destruction of natural resources or catastrophic failure due to acts of God such as earthquake or dissolution of the salt mass from subsurface waters.

From a natural resource standpoint, there are sufficient salt reserves to sustain this nation for hundreds of years. In fact, there is too much salt. Most of the major salt companies that mine salt for human consumption are operating at much less than maximum production levels. Many salt mines are standing idle due to the lack of consumer demand. More importantly, the salt being considered for hazardous waste disposal is too deep to be economically mined for consumption. Most active salt mines are relatively close to the surface, while salt deposits under study for disposal are from 3,000 to 5,000 ft deep.

Many have questioned the consequences of an earthquake should one occur in the vicinity of a hazardous waste facility in salt. Because of the composition of the salt mass—with its unique ability to move and heal itself, it is envisioned there would be little damage within the formation itself. One must remember that the energy force of a 5 kiloton nuclear device is several orders of magnitude more sudden and violent than the shifting forces of an earthquake. Secondly, because the hazardous waste will be solidified within hours of being emplaced, there will be no opportunity for the migration of hazardous fluids out of the formation even if it were breached.

Lastly, there are those who understand the process of salt dissolution from within to create caverns, but fail to understand why waters external to the salt formation will not dissolve the mass and permit exit of the waste. For 200,000 to 300,000 years, these salt masses have been in contact with subsurface migrating waters. These deep aquifers have come in contact with the salt and have become saline in the process. As a result, you find brine, but it has become so saturated with salt already that it has very little detrimental effect on the contact surface of the salt formation. However, to ensure complete safety, caverns are always created with sufficient salt buffers between the cavern and the exterior of the formation so there will be little chance of cavern failure from migrating waters.

THE FUTURE

Certainly the future will see new processes developed to reduce the amount of hazardous waste generated. The chemical industry is meeting that challenge today—trying to develop compounds that can be detoxified readily or used in another process so that hazardous waste does not become a by-product, but rather a product. Unfortunately, it takes time to conduct research, and the nation's time is running short.

Incineration, both land and sea, is costly but it offers almost complete destruction. However, there are substances that will not burn unless an inordinate amount of energy is expended to complete destruction. And, there are substances that cannot be incinerated due to toxicity or their explosive nature. Finally, even with today's best incineration capabilities, there is residue that must be placed somewhere.

Two of the cheapest forms of hazardous waste disposal—deep well injection and landfill—are coming under growing political scrutiny and their viability is being questioned. Many states have already banned deep well injection of hazardous waste. Missouri, for example, forbids the emplacement of a hazardous fluid or sludge below the surface. Kansas recently passed a law that precludes hazardous waste landfilling in the state. If this trend continues, and there is no reason to doubt that it will, the number of viable alternatives to disposal will shrink until chemical processing and incineration will be the only near term alternatives remaining. Unfortunately, both are quite expensive.

Despite the exhaustive efforts of the USEPA to regulate landfill operations and enforce compliance, many feel that current landfills will become "Superfund" sites of the future. This feeling was exhibited recently by Dr. Hirschhorn in a media interview where he stated, "The presumption of many people is that you can regulate a technology that does not work in the first place. Land disposal does not work."[5]

Deep well injection continues to flourish, but the question arises concerning the long term ability of the subsurface environment to accept massive quantities of contaminated fluids. Even the largest sponge reaches a point of saturation and will no longer accept additional moisture. And, despite the technical proof that contaminated aquifers are shielded from migrating fresh waters, one must be concerned that movements within the earth's crust, gradual or sudden, might create paths of migration allowing these fluids to join.

States such as Michigan, with over 500 contaminated drinking water wells—some of which are municipal water systems—have traced the major source of contamination to emplacement of hazardous waste in surface lands.[8] This is very unfortunate since the entire lower peninsula is underlain with massive beds of salt that are ideal for the creation of caverns. More ironic is the fact that the thickest salt beds are beneath the counties with the highest concentrations of hazardous waste generation.

It is time that the United States begins to examine another alternative, one that is environmentally safe, geologically secure and certainly more cost effective—salt.

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DISPOSAL OF SHOCK SENSITIVE/EXPLOSIVE CHEMICALS UTILIZING EXPLOSIVE DETONATION WITH OPEN BURNING

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INTRODUCTION

In February 1979, prior to the availability of commercial facilities to handle explosive and extremely reactive compounds, the New Jersey Department of Environmental Protection "Hazardous Chemical Explosives Team" developed a program to mitigate the statewide laboratory picric acid emergencies. At the request of New Jersey Emergency Response agencies, a federally permitted facility which frequently uses explosive detonation with open burning procedures to eliminate spent materials agreed to assist the state in this disposal operation. After numerous detonation operations were performed, it was determined that this procedure would prove useful in the final disposal of other materials from the cleanup of hazardous sites.

After the original picric acid incident was mitigated, the explosives team continued to provide emergency assistance to institutions across the state as a means of safely removing and disposing potentially explosive/reactive laboratory chemicals such as organic peroxides, ethers and nitrated organics.

This program has been in existence for five years. The staff of the New Jersey Explosive Team has performed this operation numerous times to dispose of thousands of pounds of explosive and reactive materials in a safe and environmentally sound manner.

DESCRIPTION OF PROBLEM

A major misconception associated with laboratory chemical storage is that chemical reagents last forever. Many laboratories have been left abandoned and many laboratory technicians have been injured because of a cavalier or unknowing attitude toward chemical storage. Laboratory storage has been and continues to be a common national problem.

The problem develops in the following manner. Laboratories purchase large quantities of chemicals to perform experiments or to develop new products. After the projects are completed, the remaining chemicals sit on shelves in the laboratory to be forgotten until the time when personnel perform inventories and discover these materials several years later and after their expiration dates. Additionally, local chemical companies donate unwanted laboratory chemicals to area high schools which will never use these materials. Many laboratory chemicals can be allowed to sit on shelves for many years without any substantial change in chemical properties, but other materials such as oxidizers, organic peroxides and ethers are not as forgiving when it comes to age, contamination and change in chemical characteristics. The problem when addressed properly and efficiently is easily resolved but, if unaddressed, develops into an extremely hazardous situation.

DISPOSAL METHODS

Detonation with open burning is a relatively new procedure for disposing of degraded potentially explosive and/or highly reactive laboratory wastes. In the past, wastes have been disposed by pouring chemicals down the drain, illegal dumping, sanitary landfill disposal or other suspect means.

Explosive detonation offers an ultimate disposal method for these materials with no chance of future explosion or reaction problems. There are many ways in which detonation can be carried out and many are dependent upon the size and shape of the containers involved. The procedures below represent the methods utilized in the authors' testing operations.

Detonation Utilizing Linear Shape Charge

The use of linear shape charge allows this procedure to be utilized on highly reactive, known-chemical, compressed gas cylinders. When gas cylinders become old, their valves sometimes become inoperable; conventional methods of disposal are useless for remedying this problem because of an inability to release the cylinders' contents.

The detonation disposal process as applied to gas cylinders works in the following manner. A section of linear shape charge is secured lengthwise on the gas cylinder and tied inline with detonation cord to two containers of flammable materials, such as heptane, acetone, etc. (Fig. 1).

When the detonation is initiated, the shape charge cuts open the gas cylinder, and, simultaneously, the detonation cord ignites the flammable materials. The fireball resulting from this explosion generates intense heat as all the combustible materials released are consumed in the flames. A main advantage in detonating these materials is that the problem of organic air contamination is minimal because of the heat and turbulence generated by the explosion. This process has been tested numerous times and has proven very effective when used on cylinders containing known pyrophoric gases.

Detonation Utilizing Military Explosives

Military explosives are preferred over commercial explosives because they are appropriately 25% stronger. Explosives such as military dynamite, composition-4 and others are utilized when detonating spent reagents containerized in glass, metal or other types of easily opened storage vessels. The process of detonating these materials is relatively simple. The materials which are to be detonated are placed in a detonation pit and are arranged in a manner to ensure that all materials are consumed in the blast. Military
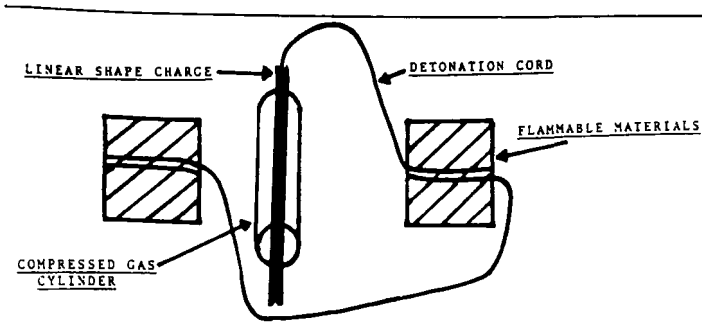
Figure 1
Compressed Gas Cylinder Linear Shape Charge Detonation Diagram
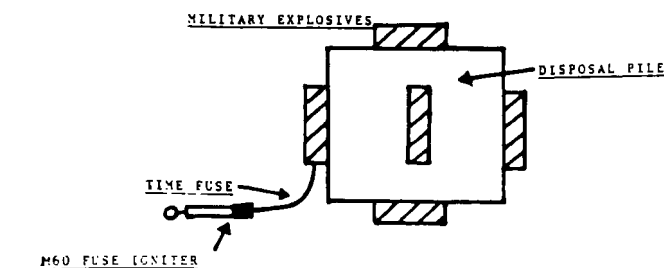
NOTE: All military explosives are tied into separate detonators for safety.

Figure 2
Military Explosives Detonation Diagram

explosives are placed around all sides of the chemical pile and an additional charge is placed on top to ensure total consumption (Fig. 2).

When performing this operation, non-electric blasting methods are utilized for initiating the charge. This allows personnel to place several charges in selected areas to guarantee initiation of the explosion. After the charges have been placed, the igniter pins are pulled and the charges are activated. Detonations of this type often do not require the use of additional flammable materials to support burning since this procedure is most often performed on ethers and other potentially explosive flammable materials. Overall, this method using military explosives has proven extremely effective as the final disposal method for numerous types of non-toxic, non-refractory potentially explosive chemical classes.

MATERIALS TESTED

Detonation disposal has been tested on several classes of degraded laboratory chemicals. The following summarizes the groups tested:
• Organic peroxides
• Inorganic oxidizers
• Pyrophoric gases
• Flammable liquids

Organic Peroxides

Commercially produced organic peroxides may be sold as solids, liquids, pastes, granules or powders. Inhibitors are added to these peroxides to reduce their flammability and potential explosive power. Organic peroxides, as they are exposed to heat or shock, degrade and become extremely unstable. This instability is caused by the volatilization or settling out of their respective reaction inhibitors. Peroxides were tested (Table 1) for this procedure be-

cause of their extremely low self-accelerating decomposition temperature (SADT).

Benzoyl peroxide reaches its SADT at 120 °F and explodes at 176 °F.[1] The initial testing was performed using the detonation with military explosives procedure. The results of these tests performed without in-line flammable materials demonstrated a high order detonation and the presence of a cloud of dense white smoke. When the same procedure was performed along with non-toxic flammable materials, a high order detonation occurred again, but the visible air emissions were substantially reduced and disposal efficiency was greatly increased.

Inorganic Oxidizers

Oxidizers such as potassium chlorate, potassium perchlorate and ammonium perchlorate produce oxygen and support combustion when involved in chemical reactions. These materials are used primarily in the production of fireworks and explosives. Oxidizing materials, when used in these tests, were detonated simultaneously with materials such as picric acid, ethyl ether, 2, 4,-dinitrophenyl hydrazine and other potentially explosive compounds. Oxidizers are primarily utilized in these operations to aid in the complete combustion of the hazardous materials which are being disposed. The test results using oxidizers produced large fireballs, great quantities of heat and reduced signs of incomplete combustion. Overall, oxidizer testing has proven useful in supplying the additional needed oxygen to aid combustion of the other in-line chemicals.

Table 1
Self-Accelerating Decomposition Temperatures of Organic Peroxides
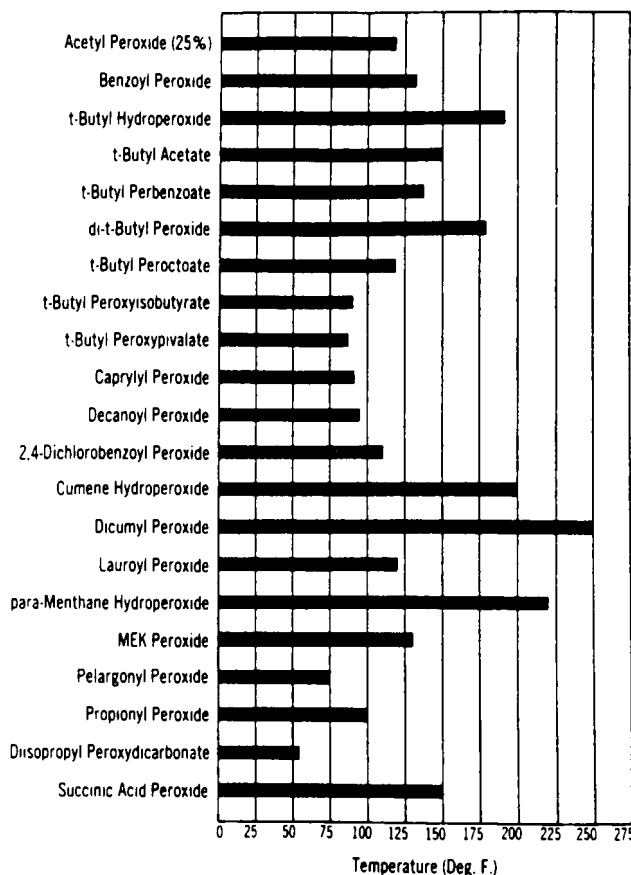
Self-accelerating decomposition temperatures (SADT) of organic peroxides 1

Pyrophoric Gases

The disposal of pyrophoric materials is a much simpler procedure compared to other materials such as peroxides and oxidizers because they ignite spontaneously on contact with air. Pyrophoric materials observed during these tests have proven to be the least difficult to dispose, primarily for the following reason: during the initial explosion, the charge forces the gases to escape the cylinder at an extremely fast rate causing a high degree of turbulence above the gas cylinder and aiding in the overall efficiency of the burn. The linear shape charge method of detonation/venting was utilized on tests involving pyrophoric materials. The results of tests utilizing di-n-butyl lithium and tri ethyl aluminum have demonstrated complete combustion and intense heat production. During actual tests involving pyrophoric gases, there were no substantial visible emissions to the atmosphere observed aside from initial formation of metallic oxide intermediates which were later destroyed.

Flammable Liquids

Flammable liquids, especially those in the ether family, represent a special problem because ethers, unless they are stored under a nitrogen blanket, are notorious for forming peroxides. These peroxides are formed as a result of oxidation initiated by heat, distillation, extended storage, degradation of inhibitors and exposure to light. Ether peroxides are extremely unstable. They have exploded after being struck by a thrown stone.[3] Ethers, in test detonations with military explosives, have been shown to produce large quantities of heat with minimal air emissions. The tests were often performed using oxidizing materials to ensure complete combustion. The disposal of flammable liquids utilizing this procedure has been proven very effective.

CONCLUSIONS

The program, which has been operative for the past five years, has been proven safe and environmentally sound. Problems may exist with incomplete combustion of some materials and the release of inorganic byproducts, but, overall, this process proves to be the best available solution to the explosive chemical problem at this time.

An additional step being investigated by the team is the incorporation of additional materials in the explosion to add heat to ensure complete combustion. The program, however, was directed toward detonation of materials which could be easily combusted. The program is presently pursuing a method for performing similar operations within a detonation chamber where testing and treatment of off-gases can be performed.

GLOSSARY

Composition-4 (C-4): Military plastic explosive consisting of cyclonite (trimethylene trinitramin) and a plasticizer, which itself may or may not be explosive.[1]

Linear Shape Charge: A plane-symmetrical hollow charge (cutting charge) is an explosive charge with a hollow space, which acts longitudinal in the plane of symmetry (roof-shaped).[2]

Detonation Cord: Explosive cord initiated by a blasting cap with a detonation velocity of 21,000 ft/sec.

SADT (Self-Accelerating Decomposition Temperature): The temperature at which the decomposition of a material proceeds by itself.[1]

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance and encouragement offered by several colleagues. In particular, they appreciate the assistance of the following: Scott A. Santora, Quality Assurance Section, New Jersey Department of Environmental Protection, Trenton, New Jersey; George R. Weiss, Hydro-Nuclear Services, Medford, New Jersey; Emergency Services Section, New Jersey State Police, Trenton, New Jersey; Ronald Decker, Bureau of Alcohol, Tobacco and Firearms, U.S. Treasury Department.

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INCINERATION OF EXPLOSIVES CONTAMINATED SOILS

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COR
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INTRODUCTION

The U.S. Army Toxic and Hazardous Materials Agency (USA-THAMA), located in the Edgewood area of Aberdeen Proving Ground, Maryland, has dual responsibility for lethal chemical demilitarization and installation restoration. It also serves as the lead agency within the U.S. Army Materiel Development and Readiness Command (DARCOM) for pollution abatement and environmental control technology development.

In this role, USATHAMA routinely conducts generic research and development (R&D) studies with wide application to current U.S. Army environmental problems. The incineration of explosives contaminated soils (IECS) project is an example of one of the many successful R&D efforts USATHAMA has conducted throughout the years.

BACKGROUND

Large quantities of wastewater are generated during the manufacturing of explosives and propellants; the loading, assembly and packing of munitions; and demilitarization and washout operations. These wastewaters (referred to as "red water" or "pink water" due to their characteristic color) contain varying concentrations of explosives. Standard practice in the past has been to dispose of these wastewaters in settling lagoons at various U.S. Army installations. Although current practice provides for in-plant treatment of these wastewaters, the inactive settling lagoons at numerous U. S. Army installations are a source of potential groundwater contamination.

USATHAMA is currently evaluating a number of potential remedial action options for future implementation. One option has emerged as the most promising in the near term (i.e., for installations requiring remedial action within the next five years). This option is excavation of the soils followed by thermal processing in a rotary kiln incinerator. The U.S. Army routinely incinerates pure explosives and propellants; however, previous to this project, this technology was undemonstrated on explosives contaminated soils.

PROJECT OBJECTIVES

The primary objective of these tests was to demonstrate the effectiveness of incineration as a decontamination method for explosives contaminated soils.

The secondary objectives of the project were to:
- Develop a data base and appropriate correlations for designing and predicting the performance of the incinerator as a decontamination method
- Determine the fate of the explosives and metals in the contaminated soils during/after incineration
- Measure pollutant levels in the stack gas to determine the air pollution control devices that would be required for future incinerators to incinerate explosives contaminated soils

Task	1982				1983											
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1 Incineration Equipment/ Test Site Selection																
2 Soil Characterizations/ Reactivity Testing																
3 Development of Detailed Test Plan/Safety Plan									U.S. Army Review							
4 Environmental Permitting - Federal - State									IEPA Review							
5 Evaluation of Materials Handling Procedures																
6 Incineration Testing																
7 Evaluation of Results																

Figure 1
Project Schedule

Table 1
Characteristics of Explosives Contaminated Soils

Description	Soil Type "A"	Soil Type "B"
Soil Matrix	Sand	Clay
Moisture Content	12-26%	25-30%
Ash Content (as received)	44-83%	54-66%
Explosives Content* (dry basis)		
— T N T	9-41%	5-14%
—RDX	0.02%	3-10%
—HMX	Not detected	0.6-1.4%
—Other	0.03%	0.06%
—Total Explosives	9-41%	10-22%
Heating Value (as received)	50-2,400 Btu/lb	600-1,200 Btu/lb

*See Table 2 for the molecular structures of the explosives.

PROJECT DESCRIPTION

In August 1982, USATHAMA commissioned the consulting firm of Roy F. Weston, Inc. to develop and implement a program to demonstrate the effectiveness of rotary kiln incineration in decontaminating explosives contaminated soils. This program had seven tasks:
- Incineration equipment/test site selection
- Soil characterization/reactivity testing
- Development of detailed test plan/safety plan
- Environmental permitting
- Evaluation of materials handling procedures
- Incineration testing
- Evaluation of results

The IECS Project Schedule is shown in Figure 1. In the following sections of the paper, the authors have presented a summary of the results of the work done.

Incineration Equipment/Test Site Selection

After a comprehensive survey of rotary kiln manufacturers to determine the availability of appropriately sized test units, Therm-All, Inc. of Peapack, New Jersey was selected as the incinerator subcontractor for the project. A major innovation of this project was the decision to use a "transportable" incinerator (i.e., equipment disassembled, loaded on trucks, shipped to the test site and reassembled) as opposed to a "mobile" incinerator (i.e., truck mounted) or shipment of the contaminated soils to a commercial facility.

The test site selected was a United States Army installation in Illinois which provided the following advantages:
- Remote location well isolated from populated areas
- Proximity to contaminated soils
- Well controlled access and security
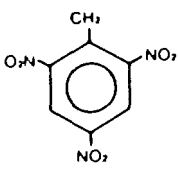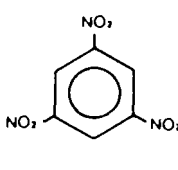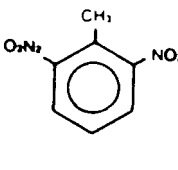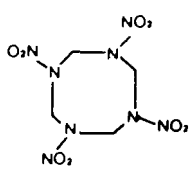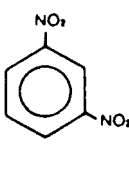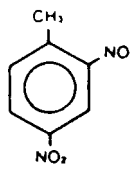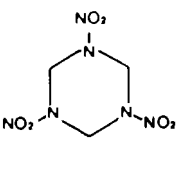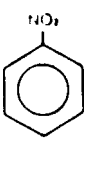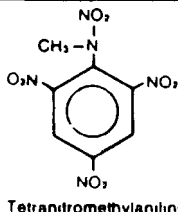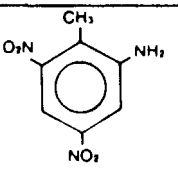
Soil Characterization/Reactivity Testing

In order to maximize the usefulness of the results of the project, USATHAMA decided to test contaminated lagoon soils from two separate installations with widely varying characteristics (Table 1). The two installations selected provided ranges of soil characteristics typical of most other U.S. Army installations.

The contaminated lagoon soils are hazardous because they exhibit the characteristic of reactivity (i.e., potential for detonation or explosion). Testing conducted at Allegany Ballistics Laboratory (ABL) in Cumberland, Maryland confirmed that the lagoon soils are reactive and that special precautions were required in developing materials handling procedures and equipment design.

Table 2
Molecular Structure of Explosives

TNT — $C_7H_5N_3O_6$ — 2,4,6 Trinitrotoluene

TNB — $C_6H_3N_3O_6$ — 1,3,5-Trinitrobenzene

2,6 DNT — $C_7H_6N_2O_4$ — 2,6-Dinitrotoluene

HMX — $C_4H_8N_8O_8$ — 1,3,5,7-Tetranitro-Octahydro-1,3,5,7-Tetracyclooctane

DNB — $C_6H_4N_2O_4$ — 1,3-Dinitrobenzene

2,4 DNT — $C_7H_6N_2O_4$ — 2,4-Dinitrotoluene

RDX — $C_3H_6N_6O_6$ — 1,3,5-Trinitro, Hexahydro-1,3,5-Triazine

NB — $C_6H_5NO_2$ — Nitrobenzene

Tetryl — $C_7H_5N_5O_8$ — Tetranitromethylaniline

2-Amino — $C_7H_7N_3O_4$ — 2-Amino-4,6 Dinitrotoluene

% O_2, CO_2, CO, HC, NO_x,
Explosives, Particulates, Metals, SO_2

% O_2, CO_2, CO, HC,
Explosives, Particulates, Metals, HCl

% Explosives
% C,H,N,S,Cl
% Moisture
% Volatiles
% Ash
% Metals
Heating Value
Total Weight

TI

TI

TI

Heat Exchanger

Fabric Filter

FI

PI

PI

Stack

Secondary Chamber

Fuel
Air

TI

% O_2, CO_2, CO, HC,
Explosives

FI

Sediment

Fuel

Rotary Kiln

FI

Air

Ash

% Explosives
% C,H,N,S,Cl
% Metals
Total Weight
EP Toxicity Testing

Particulates — % Explosives
% C,H,N,S,Cl
% Metals
Total Weight
EP Toxicity

Key
TI - Temperature Instrument
FI - Flow Instrument
PI - Pressure Instrument

Figure 2
Incineration Test Schematic Diagram

Development of Detailed Test Plan/Safety Plan

To provide meaningful evaluation of the incineration test results, a test plan was developed and certain key parameters were selected to be controlled and held at various levels during the testing:
•Soil feed rate
•Temperature in the primary combustion chamber
•Temperature in the secondary combustion chamber

The above parameters directly affected the economics of incineration, i.e., how much can be burned; how quickly can it be burned; and how much fuel is required?

Other test variables were held constant to the extent possible. Test variables that could not be held constant were measured during the test as illustrated in the test plan schematic diagram (Fig. 2).

From the outset, USATHAMA assigned personnel safety the highest priority for this project. In this regard, a detailed site plan and safety submission were developed and reviewed and approved by the Department of Defense Explosives Safety Board.

Environmental Permitting

Recognizing the importance of Federal and state environmental concerns, the IECS project was structured to be fully responsive to the requirements of RCRA and the Illinois Air Pollution and Hazardous Waste Management Regulations. As shown in the project schedule, the environmental permitting was an extremely rigorous and time consuming process.

Evaluation of Materials Handling Procedures

The primary objective of this task was to evaluate, design and implement materials handling procedures that emphasized personnel and environmental safety. There were four major goals:
•Minimize personnel contact with the lagoon soils
•Avoid confining the lagoon soils (which could lead to detonation)
•Avoid any initiating forces (i.e., friction, heating under confinement, etc.)
•Contain any spills and minimize contamination of clean areas

The test plan was developed assuming the use of a screw conveyor to feed the contaminated soils into the incinerator. However, subsequent soil reactivity testing at ABL led to cancellation of the screw conveyor due to safety considerations. A soils handling protocol and a bucket feed system was designed specificallly for this test program which met all of the test objectives and safety requirements. During the course of the test program, the feed system (Fig. 3), cycled over 4,000 times without a single failure.

Incineration Testing

The incineration testing commenced on Sept. 19, 1983. Nineteen daily tests were completed in 20 consecutive calendar days with no time lost due either to incineration or sampling equipment failure. A summary of the test conditions for each of the 19 runs is given in Table 3. Since explosive contaminated soils had never been in-
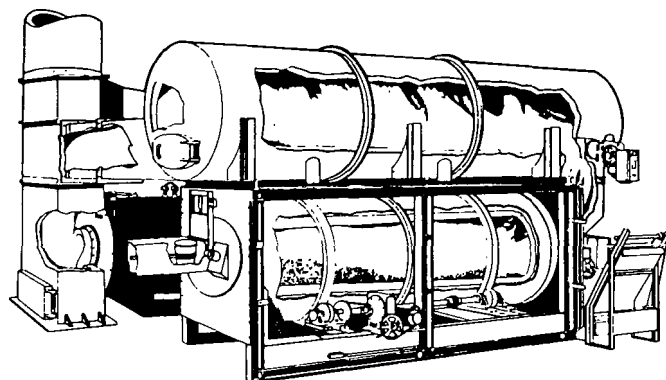
Figure 3
Cutaway Sectional View of the Thermall Incinerator

Test Run	Test Date	Matrix No.	Soil Feed Rate (lb/br)	Primary Kiln Temperature (°F)	Secondary Chamber Temperature (°F)	Soil Type (A or B)
1	9/19	0-1	500	800	1400	A
3	9/21	1-1	300	1200	1600	A
15	10/4	1-2	350	1200	1600	A
2	9/20	1-3	400	1200	1600	A
5	9/23	1-4	300	1400	1800	A
8	9/27	1-5	350	1400	1800	A
4	9/22	1-6	400	1400	1800	A
10	9/29	1-7	300	1600	2000	A
14	10/3	1-8	350	1600	2000	A
12	10/1	1-9	400	1600	2000	A
7	9/26	2-1	300	1200	1600	B
19	10/8	2-2	350	1200	1600	B
17	10/6	2-3	400	1200	1600	B
13	10/2	2-4	300	1400	1800	B
16	10/5	2-5	350	1400	1800	B
6	9/24	2-6	400	1400	1800	B
9	9/28	2-7	300	1600	2000	B
11	9/30	2-8	350	1600	2000	B
18	10/7	2-9	400	1600	2000	B

cinerated before, a preliminary test run (Test Run No. 1) was conducted at the proposed maximum feed rate (500 lb/hr) and proposed minimum primary kiln temperature (800 °F) to see if explosives breakthrough would occur in the stack gas. No explosives were detected in the stack gas; however, explosives were detected in the kiln ash, fabric filter ash and in the flue gas entering the secondary chamber. Therefore, subsequent test runs were conducted at lower feed rates and higher primary kiln temperatures to ensure that all explosives would be destroyed.

After the formal testing was completed on Oct. 8, 1983, an additional 25,000 lb of lagoon soils were incinerated from Oct. 10 to 15 (64 actual hours of incinerating soils). The objectives of burning the additional lagoon soils were two-fold:

•To thermally treat all lagoon soils that had been excavated but not required during the formal testing
•To determine the operational characteristics of the incinerator system under a long-term, steady-state production mode of operation

RESULTS

The IECS test project was extremely successful:
•It demonstrated that a "transportable" incineration system could

be disassembled, transported approximately 1,000 miles, be reassembled and be fully operational within 2 weeks

•Nineteen days of formal testing were completed within 20 consecutive calendar days with no lost time due to equipment failure

•An additional 6 days of operation were performed at steady-state conditions with no down-time due to equipment failure or malfunction

•An explosives destruction efficiency of greater than 99.99% in the primary kiln ash

•An explosives destruction efficiency greater than 99.9999 + % in the fabric filter ash

•No detectable explosives in the stack gas; therefore, an overall destruction and removal efficiency (DRE) of 100%

•Stack emissions were in compliance with all Federal and state regulations including: SO_2, HCl, NO_x, CO and particulates

•Ash residues were not hazardous using all RCRA criteria; as a result, an application was made to the Illinois EPA and the ash residues were land applied in an area adjacent to the incineration test site.

AN OVERVIEW OF "WHO IS DOING WHAT" IN LABORATORY- AND BENCH-SCALE HAZARDOUS WASTE INCINERATION RESEARCH

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INTRODUCTION

It was estimated that 57 million tons of organic hazardous/toxic wastes are generated annually in the United States, and 90% of them are disposed of by environmentally unsound methods, thus posing a serious threat to human health and the environment.[1] The Federal government responded to the critical hazardous waste problem with the enactment of the Resource Conservation and Recovery Act (RCRA) in 1976 (Public Law 94-580), Toxic Substance Control Act (TSCA) in 1976 (Public Law 94-469), and a comprehensive Superfund program in 1980 (Public Law 96-510) to assure the reliable management of hazardous/toxic waste disposal operations and dump site cleanup. The enactment of these laws has intensified research into the thermal destruction of organic chemical waste and this research has accumulated a large amount of useful information.

This paper synopsizes the past and current efforts in the area of small-scale research that has come about due to the passage of RCRA and TSCA. The purpose of this paper is to indicate "who is doing what" in the areas of incineration of hazardous wastes in terms of generating research information and in planning future programs.

The complete paper covers the following topics in great detail:

■ Past Research Activities Including:
- Non-flame Thermal Decomposition Research by the University of Dayton Research Institute (UDRI)
- Non-flame Thermal Decomposition Research by the Union Carbide Corporation
- Laminar Flame Combustion of Chlorinated Hydrocarbons by the Illinois Institute of Technology
- Thermal Destruction of Chlorophenol Residues by Environment-Canada

■ Current Research Activities Including:
- Hazardous Waste Incineration Engineering Analysis
- EPA In-House Research
- Investigation of Gas-Phase Thermal Decomposition Properties of Hazardous Organic Compounds by UDRI
- The Incineration Characteristics of Selected Chlorinated Hydrocarbons by the Louisiana State University
- Non-flame Waste Decomposition of Hazardous Waste by the Midwest Research Institute
- Heterogeneous Catalytic Oxidation of Model Chlorinated Hydrocarbons by the Massachusetts Institute of Technology

- Oxidation of Model Waste Components in Supercritical Water by the Massachusetts Institute of Technology
- Molecular Beam Mass Spectroscopic Study of Chlorinated Hydrocarbon Flames by the Illinois Institute of Technology

RESEARCH NEEDS

In 1980, USEPA published a comprehensive list of hazardous wastes,[2,3,4] One year later (1981), under RCRA, USEPA promulgated the standards for operating hazardous waste incinerators.[5] The key requirements of the standards are:
- An incinerator must achieve a Destruction and Removal Efficiency (DRE) of 99.99% for each Principal Organic Hazardous Constituent (POHC) designated for each waste feed. Initially, USEPA suggested the use of compound incinerability and concentration for selecting POHCs. It further suggested that heat of combustion (ΔH_c) be used as the measure of compound incinerability in its guidance manual to permit writers.[6]
- An incinerator burning hazardous waste containing more than 0.5% chlorine must remove 99% of the hydrogen chloride from the exhaust gas.
- An incinerator burning hazardous waste must not emit particulate matter exceeding 180 milligrams per day standard cubic meter.

A trial burn test(s) (or data equivalent to a trial burn) is required to demonstrate the ability of a hazardous waste incinerator to comply with the above performance standards.

In 1979, under TSCA, USEPA promulgated the standards for operating PCB (Polychlorinated Biphenyl) incinerators. The general requirements of the standards are:[7]
- Liquid PCBs—Maintenance of the introduced liquids for a 2-sec dwell time at 1200 °C (± 100 °C) and 3% excess oxygen in the stack gas; or
- Maintenance of the introduced liquids for a 1½-sec dwell time at 1600 °C (± 100 °C) and 2% excess oxygen in the stack gas.
- Combustion efficiency shall be at least 99.9% computed as follows:

$$\text{Combustion efficiency} = C_{CO_2}/(C_{CO_2} + C_{CO}) \times 100$$

where

C_{CO_2} = Concentration of carbon dioxide

C_{CO} = Concentration of carbon monoxide

- Non-liquid PCBs—The mass of emissions from the incinerator shall be no greater than 0.001g PCB/kg of the PCB introduced into the incinerator. (This is equivalent to 99.9999% DRE).
- Similar to the RCRA requirements, a trial burn test(s) is required to demonstrate that the incinerator meets the above standards.

Dealing with these problems requires full understanding of thermal destruction phenomena. Only on the basis of this full understanding can incineration regulations be realistically developed, and can incinerator controls be properly designed. This is why major research in incineration is needed.

In conducting its incineration research program, USEPA's Industrial Environmental Research Laboratory in Cincinnati, Ohio has set the following major research goals. All of its research efforts are aimed at achieving these goals.

Assessing Current Capabilities of Destructors

To assess the performance capabilities (Destruction and Removal Efficiencies—DREs, etc.) of existing hazardous waste thermal destruction devices (incinerators, kilns, boilers, etc.) as the technical foundation for Agency policies and regulations with respect to thermal destruction as a hazardous waste disposal option.

Defining POHCs and PICs

To provide the necessary scientific basis: (1) for selecting the appropriate Principal Organic Hazardous Constituents (POHCs) for specification in permits; and (2) for delineating those conditions of operation required to prevent the formation of hazardous Products of Incomplete Combustion (PICs).

Understanding the Thermal Destruction Process

To develop an adequate understanding of thermal destruction chemistry and the engineering of thermal processes so as to be able to: (1) characterize and assess the performance of full-scale thermal destruction devices from a minimum set of evaluative tests; and (2) extrapolate performance information from one waste type to another or from one scale or type of equipment to another (e.g., so that small-scale test burns can reliably be used in permitting decisions).

Monitoring Compliance

To define easily monitored incinerator facility operating parameters (e.g., CO/THC ratio, CO/CO_2 radio, etc.) which correlate with system performance (e.g., Destruction and Removal Efficiency, PIC formation, etc.) so as to allow rapid, reliable and economical determination by enforcement officials of compliance with permit conditions and so as to define the necessary preventive and corrective actions to avoid uncontrolled excursions from permit conditions.

Innovative Technologies

To improve the cost-effectiveness and broaden the applicability of thermal processing as a hazardous waste disposal option.

DISCLAIMER

This paper has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of USEPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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METHODS OF DETERMINING RELATIVE CONTAMINANT MOBILITIES AND MIGRATION PATHWAYS USING PHYSICAL-CHEMICAL DATA

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NEED FOR PREDICTING MIGRATION POTENTIAL

Under section 106 of CERCLA, the USEPA must provide an assessment of the health hazards presented by hazardous waste sites. The degree of rigor demanded for the assessment is dependent on the administrative and legal requirements of the USEPA. The assessment is commonly termed an endangerment assessment. The USEPA has provided recent guidance on how to conduct an endangerment assessment.[1,2] This guidance emphasizes use of physical, chemical and biological data about the contaminant to assess its potential to migrate off-site.

The endangerment assessment (EA) is intended to quantify the degree of exposure to human and environmental receptors from off-site migration of contaminants, including data on the potential for off-site migration and exposure of receptors from contaminants. Since evidence of off-site human exposure is often unavailable or difficult to measure, a demonstration of the potential for migration is crucial to the success of the EA.

In this paper, the authors describe two methods presently being used by the Ecology and Environment, Inc. Field Investigation Team to assess the migration potential of organic contaminants. A case history illustrating application of these methods is presented.

METHODS OF ASSESSING MIGRATION POTENTIAL

Mobility Index

The first method designed for assessing migration potential is the calculation of a mobility index.[3] This index produces a number that is proportional to the contaminant's probability of escaping its point of origin and migrating through the air or water. Required data include only the molecular weight, water solubility (mg/l) and vapor pressure (mm Hg). The mobility index (MI) is calculated as follows:

$$MI = \frac{\log (\text{Water Solubility} \times \text{Vapor Pressure})}{Koc} \quad (1)$$

where the Koc is the organic carbon partition coefficient. The Koc is proportional to the tendency of a dilute aqueous solution of an organic compound to adsorb onto organic carbon. Means of measuring this property have been discussed by several investigators.[4,5,6]

Published data about the Koc often are unavailable, and time and resources may preclude analytical measurement of the Koc. Fortunately, many investigators have demonstrated ways of predicting the Koc from water solubility or the octanol-water partition coefficient. The regression equation used to predict the Koc for most organic contaminants is from Kenaga:[4]

$$\log Koc = -0.55 \log(S) + 3.64 \quad (2)$$

where S is the water solubility of the compound in mg/l. The reader is cautioned that other regression equations may better predict the Koc for a particular class of organic chemicals and is referred to a discussion of this topic by Kenaga[4] or Lyman.[7]

Examining the mobility index further, one finds that vapor pressure and water solubility are proportional to mobility. For example, substances with high vapor pressure are more likely to volatilize and escape into the air while substances with high water solubility are more likely to leach into groundwater or surface waters leaving the site of origin. Substances with high Koc partition coefficients are more likely to adsorb onto soil, aquifer materials or sediment and are less likely to migrate from the site of origin. A log function is used only to reduce the size of the numbers, hence some contaminants of low water solubility or vapor pressure will have negative mobility indices.

A data-file has been created containing physical-chemical data and mobility indices for more than 100 organic priority pollutants and pesticides. Mobility indices in the data-file range from -17.0 to 6.0. Based on the distribution of these mobility indices, the following guidance on relative mobilities is offered:

Relative Mobility Index	Mobility Descriptor
>5.00	extremely mobile
0.00 to 5.00	very mobile
-5.00 to 0.00	slightly mobile
-10.00 to -5.00	immobile
<-10.00	very immobile

Equilibrium Compartment Model

A second method is used to assess mobility in a slightly different but similar way. An equilibrium compartment model is employed to predict the environmental compartments (e.g., air, water, soil, sediment and biota) most likely to accumulate the contaminant. This approach allows the user to construct a distribution profile of the contaminant in the environment and to identify the most likely pathways of migration and exposure. The model used is the Level 1 fugacity model of MacKay.[8]

The model is a simulation of the partitioning that would occur in a closed system such as a closed aquarium. After introduction of a measured amount of contaminant into a study area of known compartmental volumes, the model employs partitioning theory to predict the proportion accumulated by each compartment at equilibrium. The Koc describes the partitioning between soil, sediment and water; the octanol-water partition coefficient describes the partitioning between the biota and water; and Henry's law describes the partitioning between air and water. Data requirements are identical to those required for the calculation of the mobility index.

CASE HISTORY

The example described here involves a landfill in Colorado that had a history of receiving large quantities of liquid hazardous wastes prior to closure in 1980. It was placed in the National Priorities List in 1982. Routine site monitoring disclosed extensive groundwater contamination and established patterns of movement of the contaminated plume over time. In fact, the profile of contaminants with respect to time and location has served as an opportunity to examine the validity of the methods described above.

The physical-chemical data and mobility index for five of the major contaminants present in the groundwater at the site are found in Table 1. The distribution profiles predicted for each of the environmental compartments as derived from the fugacity model are found in Table 2. Most of the contaminants discussed here are volatile and semi-volatile solvent-type wastes, but the methods are believed to be equally applicable to base-neutral priority pollutants as well.

Table 1
Physical and Chemical Properties and Mobility Indices for Five Landfill Contaminants

Contaminant	Vapor Pressure (mm Hg)[1]	Water Solubility (mg/l)[2]	Koc	Mobility Index
1,1 dichloro-ethane	180	5500	38.0	4.41
1,1,1 trichloro-ethane	96	2440	60.3	3.59
benzene	95.2	1800	70.8	3.38
toluene	28.7	535	138.0	2.05
tetrachloro-ethylene[10]	14	175	257.0	0.98

(Superscripts 2 and 10 are references)

Table 2
Distribution Profile for Five Landfill Contaminants

Contaminant	% Air	% Water	% Soil	% Sediment	% Biota
1,1 dichloro-ethane	0.9	98.6	0.38	0.13	0.005
1,1,1 trichloro-ethane	6.6	91.3	1.60	0.53	0.01
benzene	2.4	96.4	0.93	0.31	0.007
toluene	1.3	97.0	1.30	0.43	0.028
tetrachloro-ethylene	3.8	91.6	3.40	1.13	0.038

If one assumed (incorrectly) that all of the waste was deposited at the same location at the same time, these methods should be able to qualitatively predict the relative mobility of the contaminants. For example, from these data, one would predict that the chlorinated ethanes would appear earliest in the groundwater downgradient. As the number of available adsorption sites became exhausted, benzene, toluene and tetrachloroethylene would increase.

An examination of the actual monitoring data in four downgradient wells was conducted to attempt to verify this projection. The distributions of the five contaminants in the wells with time are shown in Figures 1-5.

All of the contaminant concentrations show a general trend of decreasing concentration downgradient. Of greater interest is the change in concentration with time. Both 1,1 dichloroethane and 1,1,1 trichloroethane show an increasing concentration downgradient. Benzene and toluene, with lower mobility indices, do not exhibit this trend at this time. It is anticipated, however, that these contaminants will eventually display the same trend since they are also predicted to migrate, although at a lower rate.

Tetrachloroethylene does not fit the pattern as well. With a mobility index of 0.98, it should migrate even more slowly than benzene or toluene. Like the chlorinated ethanes, however, a noticeable trend of increasing concentration downgradient with

Figure 1
Groundwater Concentrations with Time
1,1 Dichloroethane

Figure 2
Groundwater Concentrations with Time
1,1,1 Trichloroethane

Figure 3
Groundwater Concentrations with Time
Tetrachloroethylene

Figure 4
Groundwater Concentrations with Time
Benzene

Figure 5
Groundwater Concentrations with Time
Toluene

Contaminant	Well A-105	Surface Water	Air (near A-105)
1,1 dichloroethane	6300	92	ND
1,1,1 trichloroethane	ND	720	ND
tetrachloroethylene	ND	46	ND
benzene	3600	ND	ND
toluene	6900	ND	1.5

ND means not detected.

Concentrations given in $\mu g/l$

Both air and water were anticipated to be important pathways from the application of the compartment model. This information along with the toxicity, carcinogenicity and other data helped establish the level of protection needed for on-site work. More advanced fugacity modeling is presently being applied to quantitatively predict actual compartmental concentrations. Preliminary data show good agreement between predicted and actual environmental concentrations.[9]

CONCLUSIONS

Two methods are described in order to characterize the mobility of organic compounds using physical-chemical data. One method calculates a mobility index, describing the contaminant's mobility in the environment relative to other well-known or site contaminants. The second method uses an equilibrium compartmental model to construct a profile of the distribution of the contaminant in the environment.

Data from a NPL site in Colorado were used to evaluate the suitability of these methods in characterizing environmental mobility. Groundwater monitoring of five contaminants downgradient as a function of time has shown that contaminants with high mobility indices move more rapidly in groundwater than contaminants with lower mobility indices. Limited air and water monitoring support the compartment model predictions that these media are important pathways of migration and potential exposure for the contaminants studied.

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time is evident. This difference may be due to factors other than its physical-chemical properties as discussed below. According to the relative mobility guidance suggested above, all of the contaminants would be classified as very mobile.

Factors other than those entering into calculation of the mobility index are likely to have major effects on the migration of contaminants. Seasonal fluctuations in groundwater, location and time of waste burial, biodegradation and nature of cover and contaminant practices are also very important in assessing mobility. In the case of 1,1,1 trichloroethane and tetrachloroethylene, it appears that most of these wastes were buried downgradient of well A-105.

The second prediction method involved an estimation of the partitioning behavior of the contaminants. However, from the predicted distribution, one would project that all of the contaminants would accumulate largely in the water compartment, with small but perhaps measureable concentrations in the air compartment for: 1,1,1 trichloroethane, tetrachloroethylene, benzene and toluene.

The landfill data are not complete enough in all environmental compartments to completely assess the validity of the fugacity model predictions of likely migration and exposure pathways, but qualitative evidence is available for support of the model's findings. As the previous discussion indicates, groundwaters at the site contain significant concentrations of the contaminants. Groundwater concentrations for well A-115, surface water concentrations from the January, 1984 sampling and air concentrations from 1981 sampling for the five compounds, are shown in Table 3. The water concentrations are considerably larger than the air concentrations as is suggested by the partitioning of the contaminants in Table 3.

ENDANGERMENT ASSESSMENTS FOR SUPERFUND ENFORCEMENT ACTIONS

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INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 authorizes the Federal Government to respond directly to releases, or threatened releases, of hazardous substances that may endanger public health, welfare or the environment (Public Law 96-510, 1980). Section 106(a) of CERCLA empowers the USEPA to compel responsible parties to clean up hazardous conditions through administrative or civil order. If responsible parties are not identified, the USEPA may clean a site using CERCLA "Superfund" money and seek recovery of costs when and if responsible parties are later found.

When undertaking cleanup or enforcement action at a given site, the USEPA must demonstrate whether a potentially harmful situation exists and, if so, the kind and degree of endangerment. Sections 300.64 through 300.69 of the National Contingency Plan (NCP) outline the factors that the USEPA must consider in assessing this endangerment.[5]

A USEPA endangerment assessment documents the adverse impacts that could occur given potential or actual release of hazardous material from a site. The assessment is multidisciplinary and may involve expertise from many technical areas such as chemistry, toxicology, geology, engineering, environmental modeling, demography and epidemiology.

The level of detail of the assessment depends on the kind and degree of perceived endangerment. The immediacy of risk in an emergency situation may simplify the endangerment assessment when the primary consideration is prompt mitigation of a hazard or potential for harm. When conditions allow time for more thorough evaluation, a complete endangerment assessment can be performed to better define the risk of harm and to consider options to respond to the entire problem. Information obtained through this process may be used to justify the choice of response action during litigation for cost recovery.

In this paper, the authors discuss the factors that should be considered in a complete endangerment assessment.

ENDANGERMENT ASSESSMENT FACTORS

A complete endangerment assessment involves the gathering and integration of the following information.
- Site history and management practices
- Identify, concentration and amount of hazardous substances originally on the site
- Transport and environmental fate of hazardous substances on and off the site
- Toxicological properties of the hazardous substances
- Exposure to the human population and environment

Site History and Management Practices

One of the first steps in an endangerment assessment is defining the exact location and areal extent of the site. Past and present production and disposal uses of the site should be detailed, as well as descriptions of process and containment facilities. Such management practices as process conditions, disposal methods and completeness of records should also be examined.

An assessment should contain descriptions of topographic features and locations of wells, buildings, roads and water courses. This information can be obtained from site visits and USGS quadrangle maps.

Identity of the Contaminants

It is most helpful to determine, as precisely as possible, the specific chemical contaminants that are present at a site. Such information may be available from company or government records; however, some or all of this information is often lacking.

The physical nature of contaminants known to be present should also be determined (i.e., phase, oxidation state or whether mixed or dissolved with other materials). This information may be useful for predicting the fate of the contaminants, potential exposure pathways and toxicological properties.

The amounts of hazardous substances at the site should be estimated using records of past activities. In addition, concentrations of contaminants at or near a site, in containers and in environmental media, should be analyzed. Both factors, amount and concentration, are important in defining the overall endangerment.

Samples for analysis should be taken to adequately represent the degree and extent of contamination and should be reasonable and appropriate for the situation. Comparable areas thought to be non-contaminated should also be sampled to give background or ambient concentrations for purposes of comparison. It is important that sampling and analysis are subject to strict quality control procedures to ensure the accuracy of identification and measurement.

Environmental Fate of Contaminants

An endangerment assessment of hazardous substances at a waste site requires an understanding of the likely movement, persistence and transformation of the chemicals. Predicting the fate of hazardous substances is an important step in estimating the potential exposures to humans and the environment. This prediction can be

derived from knowledge of the geology, hydrology and meteorology at a waste site as well as from the intrinsic properties of the hazardous substances.[2]

The physical and chemical characteristics of a hazardous substance affect its potential to be transported through air, soil, or water or transformed into other substances. These characteristics include molecular weight, vapor pressure, melting and boiling temperatures, water solubility, density, Henry's Law constant, octanol/water partition coefficient, adsorption coefficients, biological reactivity, absorption of visible and ultraviolet light, particle size distribution and dissociation constant.[3]

Persistence of a chemical in a specific environmental medium is an important consideration in assessing potential exposures. Persistence is a function of the degree to which it is susceptible to transformation processes including aerobic and anaerobic biodegradation, chemical reaction, complex formation, hydrolysis, heat and photolysis. Such processes may toxify or detoxify a hazardous substance or affect its ability to be transported.

Persistence is also affected by the rate of transport to other environmental media: surface water, groundwater and air. Identification and quantification of all surface water courses, ephemeral and perennial, which cross or drain the site should be done initially. Surface drainage patterns and flow rates affect the erosion of hazardous substances away from a site. Flow rates, fluctuation and pH may be measured in the field; in some cases, the data may already be published water resource documents of State and Federal agencies or may be available through computerized data bases maintained by the USGS and the USEPA.

Needed data on groundwater include the identification of the water table relative to the location of the wastes, connection to surface water, descriptions of water bearing zones or aquifers located at greater depths and quantification of these groundwater flow systems in terms of their flow rate, direction, use, point of discharge and pH. This information should be supplemented by a review of the pertinent published literature and maps on groundwater resources of the area surrounding the site. Sources of such information include State and Federal geological surveys or equivalent components within the state natural resource or environmental protection departments.

Definition and evaluation of the groundwater flow system may require installation of sufficient monitoring wells on and about the site to measure water table elevations or potentiometric heads as well as to provide access for groundwater quality sampling. Information from these wells may be supplemented by existing monitoring or water supply wells which may be located near the site. Pumping records, particularly for large industrial or municipal production wells, will yield important information on historic stress to the aquifer and possible artificial alteration of the natural water table or potentiometric surfaces.

Another important component of the hydrologic system that can affect contaminant migration is precipitation and associated infiltration. An understanding of the seasonal range of precipitation likely to fall at a site over an annual cycle is essential to an accurate determination of contaminant migration. Rainfall amounts can be obtained through continuous recording rain gauges installed at the site or from historic data collected by the National Weather Service at the nearest climatological station. Rainfall data can be used in various USEPA and other models to compute the amount of surface runoff to be expected at a site and the amount of water likely to infiltrate the site and carry contaminants to the groundwater.

The geologic environment, for the purpose of an endangerment assessment, is considered to be the soil and subsurface materials in which or upon which the hazardous waste may be located. This medium is important in terms of its controlling effects on water and contaminant transport. The physical and chemical characteristics of the geologic setting should be described and documented using the results of on-site investigations supplemented by geologic accounts in the published literature.

Soil cover at the site should be defined in terms of depths, lateral distribution and type. This information may be obtained by an appropriate grid of sample cores collected on-site, together with information from county soil surveys which may be published for the area by the USDA's Soil Conservation Service. Analyses of soil samples will yield physical characteristics such as permeability, grain size distribution and thickness as well as chemical characteristics including contaminant concentrations and natural organic and inorganic content. This information will be useful in determining presence and extent of soil contamination, availability of soil contaminants to infiltrating water, ability of the natural soils to retard contaminant migration and suitability of existing soil as cover materials for remedial actions.

Descriptions of the subsurface unconsolidated or consolidated materials, including factors such as thicknesses, lithologies, water bearing zones, hydraulic characteristics, strike, dip, areal extent and continuity and engineering properties, may be assembled from field investigation efforts and review of published literature. Studies of regional geomorphology, bedrock and surficial geology and mineral resource assessments conducted by universities, private consulting firms or State and Federal agencies all can provide valuable supplemental documentation of the critical geologic characteristics that may have a bearing on the ultimate transport and fate of contaminants migrating from a site.

Contaminants may also be transported through the air by evaporation or suspension and subsequent deposition away from the waste site. Wastes can be suspended or adsorbed on particulates. The distance particles will travel will depend on such factors as particle size, precipitation, air turbulence, wind speed and topography. Particle size also can determine the depth in the respiratory tract that a substance is deposited. The final site of deposition of a particle in the lungs can influence the toxic effect that may be exerted.

By combining knowledge of the likely movement, persistence and transformation of a hazardous substance, it is possible to predict its partitioning and distribution among environmental media at and away from a site.[4] An evaluation of the fate and transport of hazardous pollutants is crucial for developing an accurate estimate of the levels and extent to which substances have been, or continue to be, released into the environment. This estimate establishes the foundation for an exposure assessment.

Estimates of Exposure

The identification and quantification of chemicals found or expected on and off the site can be related to the surrounding populations to estimate exposures to the hazardous substances. Important factors to consider are population size and density, distance separating the site from populated areas, accessibility to the site, land use and recreational activity.

Exposure can be evaluated for the general population or for specific groups within the population. Certain high risk subpopulations should be identified, such as pregnant women, children, elderly or ill persons. Demographic information may be obtained for specific Census Bureau tracts.

The toxic effects of some chemicals may be strongly influenced by the route of exposure. Possible exposure routes include inhalation of gases or dusts, absorption through the skin from direct contact and ingestion of contaminated water, soil or food. Population characteristics and habits, as well as the amounts and concentrations of contaminants in various media, may affect the degree of exposure by each route. The behavior of the compound in a given medium should also be considered, since some substances may be bound and unavailable for absorption by the exposed persons.

The time pattern of exposure should be considered as well. The frequency, duration and timing of exposures may influence the toxic effect that a hazardous substance may exert.

Exposure to fish, wildlife and domestic plants and animals should also be assessed. One important factor to consider is the bioconcentration of certain contaminants in the food web, which can lead to increased exposures in the environment and to humans. Another important consideration is the introduction of hazardous

substances into sensitive environments such as wetlands and habitats for endangered plant and animal species.

Toxicity Evaluation

In addition to exposure estimates, information on the toxicity of the hazardous substances at a site is needed to perform an endangerment assessment. Toxic effects may be expressed in gross ways such as functional impairment, pathologic lesions or death, or in less obvious ways that may alter metabolism, immune response or behavior.

Physical and chemical properties of a substance, environmental media in which it is carried, route of exposure, time pattern of exposure and personal characteristics of exposed individuals all may influence the degree of toxic effect.

For a toxic response to occur in a person, a sufficient quantity of a substance must reach a receptor or target organ for a sufficient period of time. The response depends on the dose of the chemical, the length of exposure and transport to the receptor. Factors that affect the absorption of the chemical and its distribution, metabolism and excretion, can profoundly alter its toxicity.

Exposure to a toxic substance may produce immediate or delayed effects. The onset and severity of effects may vary from organ to organ and from person to person. Toxic effects may be exerted at the point of absorption, such as the skin, gastrointestinal tract or lungs, or may occur in distant organs following distribution, metabolism or accumulation.

A further complicating factor is that persons may be exposed to several hazardous agents simultaneously or sequentially rather than to just one. Such multi-chemical exposures may result in altered absorption, distribution and expression of effect. Chemicals often interact to produce effects either greater or less than the sum of their individual effects. When such effects are known or suspected, they should be considered in the toxicity evaluation.

Resources are available to obtain established information on the toxicity of certain substances. Controlled animal experiments using acute, subchronic or chronic exposures may have been performed to show toxic effects such as cellular or tissue changes, behavior modification, carcinogenesis, mutagenesis, teratogenesis or death. *In vitro* studies using cell cultures or bacterial assays may have demonstrated mutagenic or growth process effects. Such studies provide insight into the possible toxic effects to humans and the mechanisms of toxicity. Evidence of toxic effects in humans from exposure to hazardous substances may also be obtained from clinical reports, anecdotal reports or epidemiologic studies examining associations between specific exposures and specific disease outcomes.

There are many difficulties in interpreting existing toxicological data. Animal and *in vitro* studies require caution when extrapolating to presumed effects in humans due to such differences as body or organ size, system complexity, absorption and distribution patterns or metabolic processes. However, these studies may be the best, and often only, source of toxicity information available.

Clinical reports often describe acute or chronic effects from large doses of hazardous substances. Unfortunately, such information may not be representative of exposures at hazardous waste sites, since those exposures may be long term and low level. Clinical evidence can be suggestive of the kinds of effects that may occur at hazardous waste sites but should be interpreted with caution.

Similarly, health related anecdotal complaints of populations near waste sites should be recorded and considered but should also be interpreted with caution. Such information may be obtained from municipal or State public health departments or from the U.S. Center for Disease Control.

Epidemiologic studies may or may not show an association between exposure to a chemical or mixture of chemicals and a particular disease outcome. However, results should be interpreted with careful attention to study design and execution. Studies may be weakened by selection of improper comparison groups, misclassification of disease or exposure status, recall bias, confounding exposures to other hazardous substances or poor power to de-

tect an association. If these potential problems are minimized, valid epidemiologic data can be the most useful evidence in assessing the adverse effects of a toxic substance to humans.

In addition to human health concerns, other adverse environmental effects should be considered. Direct evidence of harm, such as fish kills, recorded declines in plant and animal populations or decreased crop yields, may be related to a hazardous substance. Adverse effects on the taste of drinking water or edible fish and shellfish, the odor and clarity of air and other aesthetic problems should also be considered.

ENDANGERMENT ASSESSMENT

Evidence of endangerment at a specific site might include documented harm to the environment, increased reports of human illness or other observable adverse effects. Endangerment also may be manifested in less evident ways or as threats of potential future harm.

To assess the endangerment posed by hazardous substances at a waste site, expected exposures to surrounding populations and the environment are compared with toxicological information. The merit of particular toxicological studies and exposure estimates should be considered since the quality of data should determine their relative importance in the endangerment assessment.

However, scientists with similar training may have widely divergent views on the interpretation of the data. These divergent views include extrapolations from high dose to low dose, extrapolations of animal data to humans, utilization of *in vitro* studies, the use of data derived from studies involving one route of exposure to another route and the health significance of certain biological effects.

Studies of toxicologic effects and dose-response relationships can be used for comparison to the estimated exposures at a specific site. It is important to determine the circumstances under which these numbers are applicable and the toxic effect for which they are derived, since misapplication can lead to erroneous assessment of endangerment. In addition, the data should be critically reviewed for methodological quality.

Toxicological indices are generally species-specific and refer to concentrations or doses that result in specific toxic effects. These indices may be found in a variety of toxicological references. Guidelines and standards for some hazardous substances have been developed by government agencies and professional organizations. These numbers generally set a limit for the level of a given substance in a particular medium that signifies no probable risk or a certain degree of risk to human health or the environment.

An endangerment assessment may be qualitative, defining the nature of potential or actual harm at a site. An assessment may also be quantitative, attempting to define the degree of risk posed by hazardous substances in terms of number of people affected and damage to human health and the environment.

For non-carcinogenic substances, lifetime exposure estimates may be compared to "acceptable daily intake" (ADI) levels or other standards appropriate to the situation.[4] ADIs are assumed to represent the dose that is without probable risk when taken daily for life. They are generally derived from doses which were observed to have no toxic effect in animals, corrected by a safety factor that reflects whether the data are from humans or animals, the quantity of data and the existence of sensitive subpopulations. Endangerment is assessed from a comparison of the estimated exposure and the ADI (or other guideline) for a given non-carcinogenic substance.

For carcinogens, the USEPA does not define a threshold response level. Rather, any amount of exposure is expected to pose a certain degree of risk. These risks are quantitatively calculated from the estimated magnitude of exposure and the potency of the carcinogen, if known.

Some aspects of the methodology for defining carcinogenic risks are controversial, such as the choice of model for risk estimation. A number of models exist, using a variety of mathematical func-

tions, each with a biological basis used to justify its form. The main difference among these models is the shape of the dose-response relationship as the exposure decreases.

Until November 1980, the USEPA Cancer Assessment Group (CAG) used a linear, non-threshold, one-hit model to estimate cancer risk.[3] Following public comment, CAG later adopted a linearized, non-threshold, multi-stage model for the extrapolation since it appears to be the most general and biologically plausible method.[1] The calculated carcinogenic risk is the probable upper bound of risk. The estimate is conservative, and the true risk is not likely to exceed it.

The qualitative and quantitative endangerment assessments developed through this process are valuable in defining the kind and degree of risk posed by hazardous substances at a waste site. They are also useful in providing guidance for remedial alternative selection and for justifying that choice.

This discussion of endangerment assessment has been necessarily general. The wide variety of chemicals found from site to site and the range of site conditions require site-specific assessments that preclude more detailed guidance.

The adequacy of, and confidence in, an endangerment assessment is highly dependent on the quality of sampling, analyses, fate predictions, exposure estimations and toxicology data. At all stages of an assessment, careful attention must be paid to the methodology and executive of information collection. Interpretation of this information involves a great deal of judgment and should reflect sound scientific principles and a commitment to the protection of public health and the environment.

CONCLUSIONS

An endangerment assessment at a hazardous waste site should integrate knowledge of the toxicological effects of hazardous substances with the estimated environmental and human exposures to these substances. Exposures are estimated based on site character-

istics, contaminant properties, hydrogeological conditions and environmental measurements. Strict quality control is important in the collection of data, and sound scientific judgment is required in interpretation. The USEPA performs these assessments to determine appropriate emergency or remedial responses and to justify these actions.

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MIGRATION AND DEGRADATION PATTERNS
OF VOLATILE ORGANIC COMPOUNDS

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INTRODUCTION

Volatile organic priority pollutants have been detected in groundwater all across the country. These compounds, widely used as solvents, are considered environmentally mobile and persistent. Improved analytical methods using gas chromotography and/or mass spectroscopy now allow their detection at extremely low levels. The presence of the synthetic organics in groundwater coupled with an improved ability to detect them has resulted in increasing numbers of contamination investigations.

Biodegradation is not typically an integral part of today's groundwater investigations. There is considerable controversy regarding whether degradation is an important factor in determining the fate of the chlorinated volatile organic priority pollutant. Increasing evidence indicates chlorinated solvents can be degraded in an anaerobic environment by reductive dehalogenation. It is reported this process occurs when the oxidation/reduction potential is less than 0.35V. The sequential removal of chlorine atoms from halogenated 1 and 2 carbon aliphatic compounds results in formation of other volatile, chlorinated priority pollutants which can be detected during investigations of solvent contamination.[1,2,3]

In this paper, the authors present data from a variety of sites having documented chlorinated solvents contamination. Three types of sites were selected to illustrate breakdown patterns which may develop as a result of diverse environmental conditions. Data from landfills are presented to demonstrate presence of degradation products in biologically active anaerobic environments. Two solvent recovery facilities which handle both chlorinated and non-chlorinated solvents showed similar migration and degradation patterns. Finally, an industrial site with no apparent degradation demonstrates conditions in which reductive dehalogenation may not be a primary degradation mechanism.

Research data indicates chlorinated solvents have varying rates of breakdown. The data were therefore evaluated for a dominance of compounds which show longer half-lives, including 1,2-dichloroethenes and vinyl chloride.[4]

BACKGROUND

For purposes of this evaluation, selected compounds were designated as "parent" compounds based on their widespread use and/or known presence at these specific sites. They include methylene chloride, 1,1,1-trichloroethane, trichlorethene and tetrachlorethene.

Breakdown products are designated as compounds which would result from reductive dehalogenation of these parent compounds and include dichloroethanes, chloroethane, dichloroethenes and vinyl chloride. For purposes of this evaluation, methylene chloride

is disregarded, since it is a commonly used solvent, potential degradation product and common laboratory contaminant. Emphasis is placed on the ethene and ethane series because there is less ambiguity in the assignment of parent and breakdown products. The anaerobic breakdown sequence for the chlorinated ethenes and ethanes via reductive halogenation is shown below:

Chlorinated Ethenes

$$\text{Tetrachloroethene}_1 \longrightarrow \text{Trichlorethene}_1 \overset{\underset{Cl}{\uparrow}}{\longrightarrow} \begin{matrix} \overset{Cl}{\underset{\uparrow}{}} cis\text{-}1,2_2 \\ trans\text{-}1,2_2 \\ 1,1\text{-}_1 \\ dichloroethene \end{matrix} \overset{\underset{Cl}{\uparrow}}{\longrightarrow} \text{Vinyl Chloride}_2 \quad (1)$$

Chlorinated Ethanes

$$1,1,1\text{-Trichloroethane}_2 \overset{\underset{Cl}{\uparrow}}{\longrightarrow} 1,1\text{-dichloroethane}_1 \overset{\underset{Cl}{\uparrow}}{\longrightarrow} \text{chloroethane}_1 \quad (2)$$
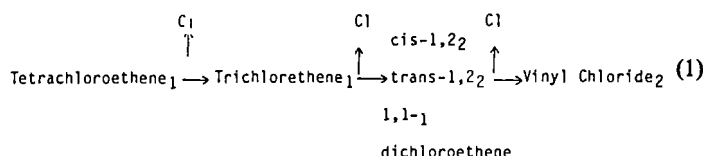
1. Research indicates substantial degradation.
2. Research indicates degradation is slow.

In work performed at the Florida International University by Parsons, Wood and DeMarco,[1] biodegradation of either trichloroethene or tetrachloroethene produced higher concentrations of cis- 1,2-dichlorethene when compared to the trans-isomer.

Trans-1,2-Dichloroethene is a priority pollutant and has a lower allowed concentration in drinking water (272 μg/l) than the cis-isomer (400 μg/l).[5] USEPA's rationale for selection of the trans-isomer as the priority pollutant was based on the availability of the analytical standard.[16]

DATA PRESENTATION

In the authors' first attempts to correlate the ethene breakdown series with data from contaminated sites, it became apparent that the dominant dichloroethene compound detected was trans-1,2-dichlorethene. The cis-isomer is not a priority pollutant and, therefore, is not mentioned in the methods for analysis of the volatile organic priority pollutants using Method 601 or Method 624.

These methods recommend the use of a column composed of 1% SP 1000 on Carbopack B. The isomer pair cannot be separated using the above column. In addition, since they have identical mass

spectra, the isomer pair will not be differentiated by mass spectrometry and will subsequently be identified as the trans-isomer.

The above theory was verified by the submittal of a standard mix containing both the cis- and trans-isomers to a prominent midwestern laboratory. Analysis by Method 624 found only the trans-isomer, but the quantitated result equalled the known total of the isomer pair.

The Michigan Department of Health can separate the cis- and trans-isomers and, in a current investigation, has determined that the major contaminant at a site is not trans-1,2-dichloroethene as found by a USEPA contract laboratory, but is the cis-isomer. They have indicated that frequently they find the cis-isomer and, if concentrations are high, they occasionally find traces of the trans-isomer.

Based on this information, the authors conclude that much of what is typically reported as the trans-isomer, which is a priority pollutant, is in fact cis-1,2-dichloroethene. In the subsequent evaluations, the authors will refer to these compounds as 1,2-dichlorethenes.

Landfills

Landfills which accept municipal waste have an anaerobic environment in which substantial breakdown of compounds occurs. At sites which have also accepted waste products containing solvents, a number of volatile organic priority pollutants can be detected in the leachate. The analyses of five leachate samples from Site #1 which accepted both municipal and industrial wastes are found in Table 1. The site also received significant quantities of hazardous and nonhazardous liquid wastes. Based on records of waste accepted, there is a dominance of "breakdown products" at this site.

The amount of breakdown products detected in groundwater at two other sites where volatile organic contaminants have migrated off-site is shown in Table 2. Site #2 is a small municipal landfill in a sand and gravel environment and Site #3 is a large clay-lined site which has accepted waste similar to Site #1. At these sites, the authors have also documented a dominance of the breakdown products in groundwater downgradient from the waste disposal boundaries.

The purpose of presenting leachate data from these landfills is to demonstrate that in an anaerobic, high-organic matrix, one is likely

Table 1
Landfill Leachate, Site #1

	Leachate Sample Number				
	1	2	3	4	5
Chlorinated Ethanes					
1 Trichlorethanes	NO3	68	ND	ND	ND
2 1,1-Dichloroethane	1,500	240	130	11	13
1,2-Dichloroethane	ND	12	21	ND	ND
Chloroethane	ND	21	18	160	ND
Chlorinated Ethanes					
1 Tetrachloroethene	ND	13	ND	ND	ND
Trichloroethene	ND	100	62	ND	ND
2 1,2-Dichloroethenes	3,200	990	950	150	ND
1,1-Dichloroethene	ND	ND	ND	ND	ND
Vinyl Chloride	ND	120	59	100	ND
Other Volatile Priority Pollutants					
Methylene Chloride	5,300	120	770	ND	14
Toluene	2,000	410	650	460	58
Benzene	ND	30	37	110	16
Ethylbenzene	ND	93	64	140	68
1,2-Dichloropropane	ND	18	37	ND	ND

1. Parent Compounds   3. ND — <10 µg/l
2. Breakdown Products   4. All Concentrations in Mg/l

Table 2
Breakdown Products Present in Contaminated Groundwater Near Disposal Facilities

	Site #2	Site #3
No. of Samples from Wells showing Solvent Contamination	10	8
No. of Samples with 50% Breakdown Products*	2	0
No. of Samples with 50-75% Breakdown Products*	3	0
No. of Samples with 75-100% Breakdown Products*	5	8

*Breakdown defined as monochloro- and dichloro- ethanes and ethenes compared to total chlorinated ethanes and ethenes.

to find compounds which are a result of reductive dehalogenation. It is unlikely that these compounds were the dominant disposal compounds at these sites based on site records, general production and common use. Of particular interest is the fact that all eight of the leachate samples from the large co-disposal facility were comprised of greater than 75% breakdown products.

Solvent Recovery Facilities

Solvent recovery facilities handle a wide variety of organic compounds including chlorinated solvents. In addition, varying hydrogeologic conditions can result in complex migration patterns. The two facilities discussed in this section differ in operation and location, but have similarities in migration and degradation patterns. Geologic and hydrologic characteristics at these solvent recovery facilities are given in Table 3.

Table 3
Solvent Recovery Site Geological Conditions

	Site 1	Site 2
Location	Connecticut	Wisconsin
Date of Investigation	1980	1983
Geology	Alluvial sands and gravel in relatively impermeable bedrock valley	Thick, sandy glacial till deposits overlying limestone bedrock
Hydrology	Shallow groundwater, 10 ft, alluvial sands constitute primary municipal aquifer	Till supports only minimal ground-withdrawal, permeability approx 10⁻⁴ to 10⁻⁵ cm/sec. Limestone is aquifer in the area.

The analytical data for the above sites are found in Tables 4 and 5. Both sites handled chlorinated and nonchlorinated solvents. High concentrations of both the chlorinated and nonchlorinated compounds were present near the on-site handling areas. The off-site contamination showed a dominance of the chlorinated compounds. Nonchlorinated compounds detected were priority pollutants. In cases where analyses were performed, the presence of compounds like toluene and benzene were indicative of a much higher concentration of other nonpriority pollutant hydrocarbons.

At the Wisconsin site, dichlorethanes, dichlorethenes and vinyl chloride were detected in significant concentrations in the groundwater. These compounds were not handled at the facility, and this is supported by records of routine gas chromatographic analyses at the recycling facility. Further evaluation failed to indicate the presence of other possible sources of the breakdown products. Information was not available to evaluate this question at the Connecticut site.

An evaluation was then performed to assess whether data from these facilities show patterns which would be a result of anaerobic degradation. The evaluation includes an analysis of the percentage of breakdown products measured at the source and at a downgradient location.

To illustrate trends, the data have been summarized in Figure 1. Results are shown for the priority pollutant analyses for a water

table well and piezometer located on-site that had the highest concentrations, as well as a downgradient water table well and piezometer. At both of the sites, primarily horizontal hydraulic gradients were observed during the hydrogeological assessment based on water level measurements. Elevated concentrations of contaminants were anticipated at the downgradient water table wells.

Table 4
Solvent Recovery Operations
Summary of Volatile Organic Priority Pollutants Detected at
On-Site and Downgradient Piezometers: Connecticut Site

| | On-Site | | 250' Downgradient | |
	Water Table	At Depth	Water Table	At Depth
Chlorinated Ethanes				
1 1,1,1-Trichloroethane	ND3	3,700	260	ND
2 1,1-Dichloroethane	8,300 .	3,000	2,500	ND
Chlorinated Ethenes				
1 Tetrachloroethene	2,900	ND	34	ND
Trichloroethene	39,000	330	ND	ND
2 1,2-Dichloroethenes	30,000	2,700	ND	4,300
1,1-Dichloroethene	ND	ND	ND	ND
Vinyl chloride	ND	200	NO	2,700
Other Solvents Detected				
Methylene Chloride	100,000	7,000	25	3,900
Ethylbenzene	12,000	440	ND	3,700
Toluene	34,000	5,100	ND	7,600

1. Parent Compounds   3. ND — $<$ 10 μg/l
2. Breakdown Products   4. All Concentrations are in μg/l

Table 5
Solvent Recovery Operations
Summary of Volatile Organic Priority Pollutants Detected at
On-Site and Downgradient Piezometers: Wisconsin Site

| | On-Site | | 250' Downgradient | |
	Water Table	Depth	Water Table	Depth
Chlorinated Ethanes				
1 1,1,2,2-Tetrachloroethane	19,000	ND3	ND	ND
1,1,2-Trichloroethane	ND	ND	ND	60
1,1,1-Trichloroethane	22,000	270,000	ND	20,000
2 1,2-Dichloroethane	ND	ND	ND	230
1,1-Dichloroethane	ND	6,200	ND	5,100
Chloroethane	ND	ND	ND	90
Chlorinated Ethenes				
1 Tetrachloroethene	ND	22,000	ND	610
Trichloroethene	63,000	250,000	ND	1,000
2 1,2-Dichloroethenes	30,000	8,700	ND	47,000
1,1-Dichloroethene	ND	ND	ND	720
Vinyl Chloride	ND	ND	ND	210
Other Solvents Detected				
Methylene Chloride	230,000	170,000	ND	20,000
Benzene	12,000	ND	ND	20
Ethylbenzene	28,000	9,200	ND	630
Toluene	100,000	42,000	ND	4,100

1. Parent Compounds   3. ND — $<$ 10 μg/l
2. Breakdown Products   4. All Concentrations are in μg/l

The figure shows the total volatile organic concentrations detected at the above described well locations for both sides and the percentage of breakdown products compared to the sum of the chlorinated ethanes and ethenes.

Both of the sites exhibited high levels of chlorinated organic contamination at the source. Nonchlorinated organics were also present at the sources in high concentrations, providing a nonchlorinated carbon source. These nonchlorinated organic compounds were present in highest concentrations at the water table. At the Wisconsin site, a floating layer of fuel oil type material was detected at one well.

With distance downgradient from the source, the contaminants were detected at greater concentrations with depth even though groundwater flow was near horizontal. There are various explanations for this phenomenon, including changing groundwater flow
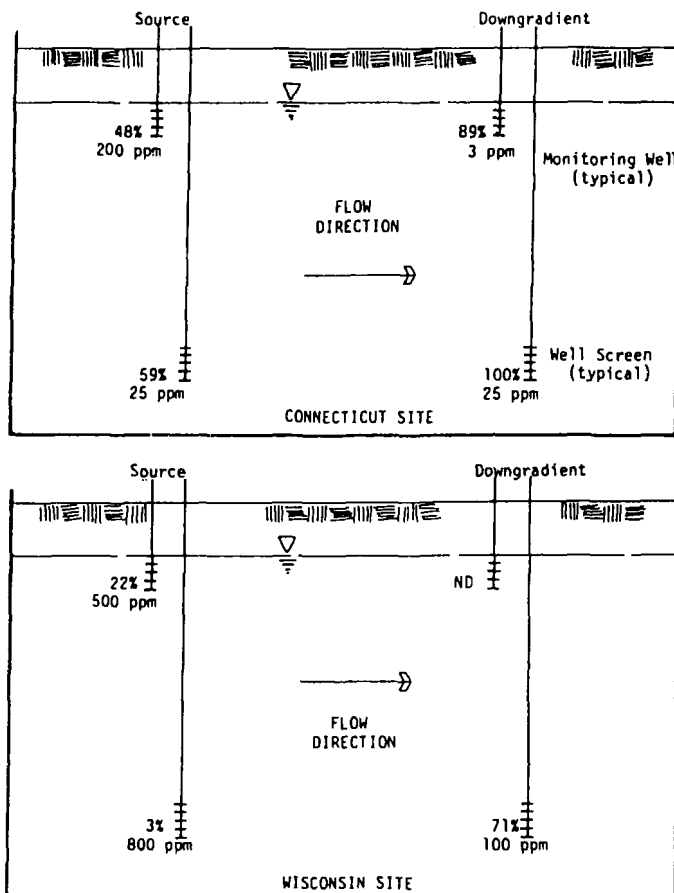
% Values = % Breakdown Products   ppm Values = Total of all Volatile Priority Pollutants

Figure 1
Anaerobic Breakdown Patterns of Organic Materials

patterns, recharge or impermeable barriers which may have hampered migration of contaminants to the water table wells.[6] These parameters will be evaluated further with additional hydrogeologic study, where funding is available.

Other explanations include density effects, volatilization and selective degradation. It is well documented that chlorinated compounds will sink in the aquifer at the source when in excess of the solubility of water.[7] For subsequent density effects to be apparent in the contaminated groundwater where concentrations are lower, the overall density of that solution must be greater than that of background water quality. Preliminary calculations indicate that at the concentrations measured at the sites, the density difference would not be sufficient to account for sinking of the contaminated groundwater plumes.

The USEPA had indicated that a primary environmental fate for these compounds in aquatic systems would be volatilization.[8] Factors which affect volatilization of these compounds from a ground-

water system include: soil porosity and temperature, depth to water table and the various solubilities of the compounds in water. Although it is recognized that some volatilization will occur, it is not expected to be a primary fate of organics at these sites.

Selective degradation is presented as another possible explanation for preferential loss of the constituents at the water table wells. The biodegradation of chlorinated compounds may be affected by the co-metabolism of other carbon sources. Solvent recovery operations can provide a nonchlorinated carbon source which tends to accumulate near the water table surface. These compounds are typically not detected with distance from the source, due to rapid breakdown and may be responsible for preferential loss of the chlorinated compounds from the more shallow zone of the aquifer.

The breakdown of the chlorinated compounds can occur rapidly in the presence of a nonchlorinated carbon source which promotes rapid co-metabolism to dehalogenate the chlorinated compounds. The data suggest that degradation continues to occur deeper in the aquifer, perhaps at a slower rate.

Industrial Site

For purposes of contrast with sites which have high levels of contamination and a substantial carbon source, the authors have presented data from an industrial site having primarily sandy soils, shallow groundwater and little or no detectable nonchlorinated organic priority pollutants (Table 6).

Table 6
Industrial Site Solvent Contamination of a City Well

Well	1,1,1-Trichloroethane	Trichloroethene	1,1-Dichloroethene
1	ND	81	ND
2	13,800	2,040	250
3	2,660	410	ND
4	7	1	ND
5	8	2	ND
6	ND	68	ND
7	10	12	ND

1. All Concentrations are in µg/l   2. ND — $<$ 1 µg/l

Three major contrasts with data from the solvent recovery facilities are noted:
•Overall contaminant concentrations detected are lower and all compounds are chlorinated
•A dominance of the parent compounds exists
•The plume was detected in highest concentrations at the water table wells. The lack of a significant carbon source to promote degradation can account for the minimal breakdown occurring at the industrial site

CONCLUSIONS

Parameters which would assist in determining biodegradation activity are typically not incorporated into standard hydrogeologic investigations. A better understanding of the role of degradation could be obtained through a more comprehensive investigative program including biological assessment as well as the standard groundwater flow and chemistry analyses

Data from the authors' investigations suggest that if a site has a substantial carbon source, anaerobic degradation will occur, resulting in the formation of dichloro- and monochloro- ethane and ethene compounds. The presence of these compounds follows the predictions in the literature regarding the degradability of the parent compounds. In addition, the dominance of the cis-isomer of 1,2-dichloroethene formed during degradation will result in its presence in these investigations rather than the priority pollutant trans-isomer.

A floating organic layer near a contamination site may enhance the rate of degradation near the water table as the chlorinated compounds would more readily be co-metabolized in that zone of the aquifer.

RECOMMENDATIONS

At sites where degradation is indicated, additional measurements should be made to better understand the potential role and controlling mechanisms of biodegradation. This would include measurement of the overall organic content in water or soil and measurements of oxidation reduction potential (Eh), oxygen concentration and plate counts of bacteria.[11,12,13,14,15] Density measurements of the contaminated groundwater will allow clarification of potential density effects on migration patterns. During interpretation of the data, one can evaluate the presence of breakdown products and the pattern of their occurrence in relation to the parent compounds. One should report "1,2-dichloroethenes" without specifying the specific cis- or trans-isomer, unless that specific distinction can be made by the analytical laboratory.

It is hoped that increased awareness of the conditions under which maximum degradation can occur will improve the approach and substantially increase the conclusions which can be drawn from groundwater contamination investigations.

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SITE ASSESSMENT UNDER CERCLA: 'THE IMPORTANCE OF DISTINGUISHING HAZARD FROM RISK'

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INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) otherwise referred to as "Superfund" was established to provide a mechanism for the timely identification and remediation of hazardous substance releases. The Act functions by providing a fund for the cleanup of waste emergencies and makes provisions for the allocation and recovery of resources regardless of the existence or willingness of parties responsible for the release. CERCLA places government agencies or their assigned designees in a lead position investigating hazardous waste sites and emergencies to specify remedial responses and initiate their implementation.

CERCLA and its procedures document, the National Contingency Plan, specify that response to implemented in cases where an imminent and substantial threat to health, human welfare and the environment has been determined to exist. Remediation is to be conducted in a cost-effective manner focused on reducing risks to acceptable levels. The working and intent of Superfund indicate that responses are to be directed toward actual site risks, and acknowledges the existence of acceptable levels of risk.

Crucial to the effective implementation of CERCLA is the distinction between chemical hazards and site risks. Whereas chemical hazard is an inherent characteristic such as toxicity, or reactivity or environmental persistence, risk is a site or incident-specific probability term. Site risk considers chemical hazards and a number of site related hazards, and represents the probability of a given deleterious effect occurring. Many improperly disposed chemical compounds can be extremely toxic but become so strongly bound to soil particles or too rapidly degraded that they constitute no substantial risk to nearby populations. In other cases, a toxic chemical may be released from a site but represents a very low risk due to the absence of exposed human or wildlife populations in zones where toxic levels of the material exist. Both cases represent uncontrolled hazardous chemical waste conditions with a low probability or risk of causing harm.

A specific charge of the National Contingency Plan was the compilation and publishing of a graded list of uncontrolled chemical waste sites requiring immediate attention under CERCLA, known as the National Priorities List. Most sites on the list were compiled using a hazard ranking system known as the MITRE model detailed in the National Contingency Plan. It is important to note that the MITRE model is a generic method of ranking site hazards using a minimum of information and is not indicative of actual risks of harm to human health or the environment. Inclusion on the list indicates a situation that, due to some of its hazard characteristics requires more detailed attention. Further assessment is conducted during the site Remedial Investigation/Feasibility Study.

THE REMEDIAL INVESTIGATION

The determination of actual risks arising as a result of a given uncontrolled hazardous waste situation is the product of the Remedial Investigation. The risk assessment may be the most useful criterion used in determining the level of remediation, if any to be implemented. Elements of a Remedial Investigation contributing to an accurate risk estimate are a thorough characterization of the waste materials deposited at the site, information on the physical and hydrological characteristics of on-site and offsite areas and accurate analytical chemical data on the levels of contaminants of concern in media leaving the site. The establishment of risk requires a source of toxic chemical, a working mechanism which transports the chemical from the site to offsite areas and the existence of potential for exposure of human or wildlife populations. The source, transport and affected population or "receptor" components each represent a hazard term. No single hazard component can stand alone to describe the level of risk arising as a consequence of a waste site. The three components must act in concert before the situation is such that it represents an imminent risk requiring response under CERCLA.

INHERENT WEAKNESSES OF COMPREHENSIVE ANALYTICAL SURVEYS

In many investigations, activity begins by performing an analytical chemical survey of the site and some offsite areas. This approach attempts to unify the source, transport and receptor components of risk by demonstrating that chemicals are present in all three compartments. Very often the objective of the survey is to detect and identify as many chemical components as possible. However, complete characterization of a given environmental sample by non-specific analytical chemical techniques is a difficult task which cannot address all classes of compounds with an equal degree of accuracy. Problems arise as a result of the large number of chemical compounds and matrix interferents which may be present in the waste mixture or environmental sample. Differences in their relative concentrations extractability, recovery and chromatographic behavior during various cleanup, concentration, and separation steps of the analysis make detection and accurate determination of each component unlikely.

Even analytical protocols utilizing elaborate mass spectral libraries can only detect and identify a fraction of chemical compounds. The EPA Priority Pollutant scheme is one of the most sophisticated multi-component analytical protocols in routine use today, yet it can provide a false sense of security to investigators
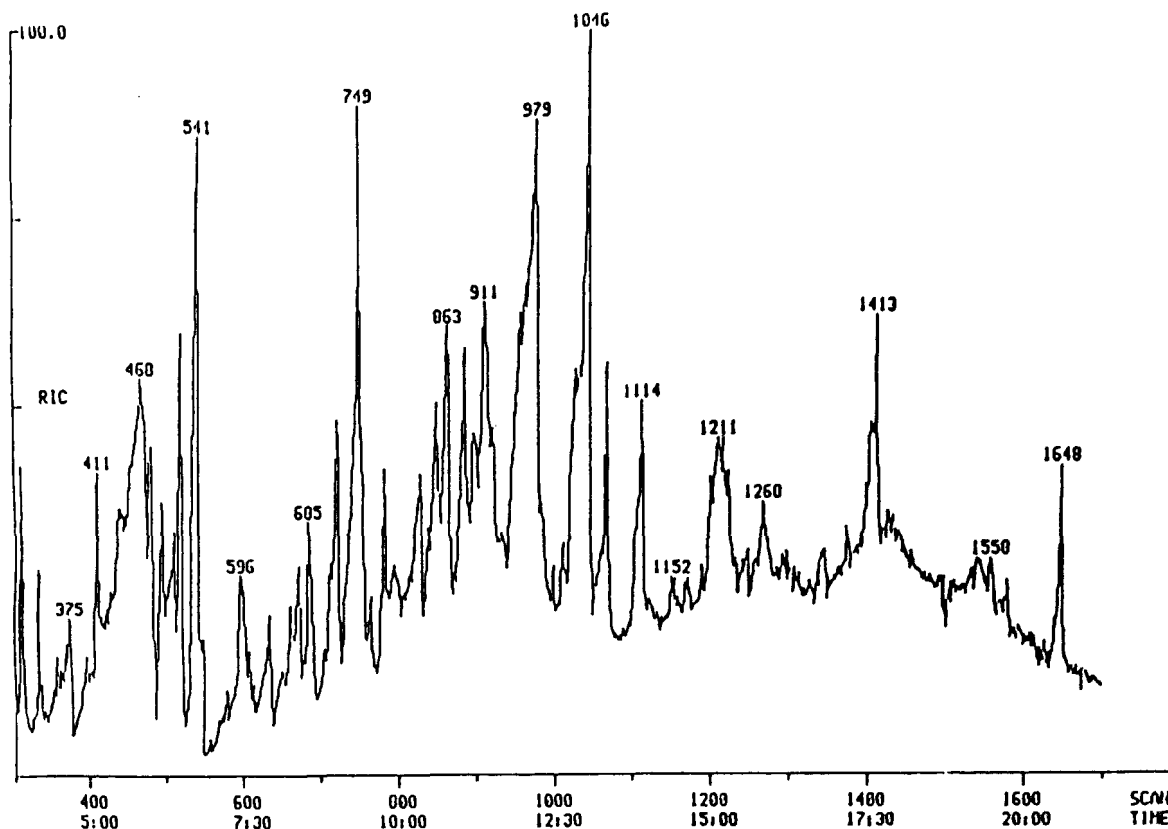
Figure 1
Gas Chromatogram of Base-Neutral Extract

utilizing it as a criteria for site characterization. Figure 1 is a reproduction of a base neutral priority pollutant scan of a groundwater sample collected near an uncontrolled waste site. The sample contained over 1,000 parts per million of Total Organic Carbon (TOC). The analytical report indicated that no priority pollutants were present at a limit of detection in the low part per billion range. Yet it is evident that a significant number of chemical compounds have been detected. Computer matching of the mass spectra of each peak yielded only two identifications with an acceptable probability of positive identification. Further identification is limited because few analytical laboratories providing mass spectroscopic services are able to furnish manual interpretations of mass spectra within reasonable constraints of technical validity, time and cost. Even if complete chemical characterization were possible, the investigator would be left with a set of chemical compounds whose hazards need to be evaluated.

FORMULATION OF SITE-SPECIFIC PARAMETERS

In light of the limitations of Priority Pollutant scheme and the absence of an analytical technique capable of detecting, quantifying and providing comprehensive identification of components in a waste mixture or environmental sample, the remedial investigator might be well justified in reducing his dependence on the analytical chemist as a provider of primary data for use in preliminary investigations. An alternate approach is a thorough review of the site history and activities with the intent of formulating a set of site-specific indicator compounds. This set is to represent those materials whose combination of physicochemical and toxicological properties are unique from the other waste components in a way that establishes biological consequences of exposure and facilitates transport by the movement of air or water.

The site-specific compound review is favored because it addresses the source, transport and toxicological hazard characteristics of the waste components and does not require a comprehen-

sive analytical search for the entire set of materials handled on the site. It narrows the field of chemicals to a few compounds with a known identity for which specific analytical protocols can be designed and carried out within acceptable quality control criteria; yet it does not limit itself to the Priority Pollutants.

The formulation of a site-specific indicator compound list is initiated by careful review of the history of the site. This approach is most successful when investigations are conducted with the cooperation of site owners and site history information is available. Review consists of collecting and interpreting information on production processes, the raw materials and likely waste products of the processes, their volumes and the waste disposal practices employed on the site. The product of the initial task is a list of chemical compounds most likely to have been disposed or otherwise distributed about the site through production activities.

The list of materials is then evaluated for toxicity and physicochemical characteristics which can, in combination with a transport mechanism such as groundwater movement, function to facilitate transport to receptors. Chemical characteristics evaluated are the materials reported acute and chronic toxicity and key physicochemical constants controlling environmental fate and mobility, such as, vapor pressure, water solubility, octanol-water partition coefficient (K_{ow}), chemical reactivity and biodegradability. Data on these parameters can be retrieved from chemical handbooks[1, 2] and primary references as well as calculated by physical chemical property estimation techniques.[3]

The toxicity of a component is a term which initially stands alone for evaluation. Toxicity information can be retrieved from standard reference books,[4] or by use of databases such as DIALOG or TOXLINE. If a compound is determined to be of low toxicity, it does not need to be considered further for inclusion on the indicator parameter list. A compound determined to have hazardous toxic properties is further evaluated for properties favoring offsite transport.

Table 1
Site Specific Indicator List

CHEMICAL NAME	WATER SOLUBILITY at 20°C	VAPOR PRESSURE at 20°C	BIODEGRADABILITY	TOXICITY	LOG KOW
Styrene	300 mg/l	5 mm Hg	BOD_5 65% ThOD	Fathead Minnow 48 hr TLm=53.6 mg/l Rat Oral Acute LD_{50} 1 g/kg Animal Positive Carcinogen Human Suspected Carcinogen Aquatic Toxicity Rating TLm96:100-10ppm	Log Kow = 2.95
Phenol	82 g/l	0.2 mm Hg	200 ppm; 57% degraded within 5 days Bacterial inhibition at 64 mg/l	Aquatic Toxicity Rating TLm 96:100-10 ppm Oral Rat LD_{50} 414 mg/kg Fathead Minnow LC_{50} 40 mg/l	Log Kow = 1.46
Benzene	1,780 mg/l	76 mm Hg	BOD_5 10% ThOD Slow Bacterial Inhibition at 92 mg/l	Aquatic Toxicity Rating TLm 96:100-10 ppm 96 hr = 32 mg/l Rat Oral LD_{50} 4,894 mg/kg Human Positive Carcinogen Animal Suspect Carcinogen	Log Kow = 0.00
Ethyl Benzene	152 mg/l	7 mm Hg	Slow Inhibits Bacteria at 12 mg/l	Fathead Minnow TLm96:48 mg/l Rat Oral LD_{50}= 3,500 mg/kg Aquatic Toxicity TLm=100-10 ppm	Log Kow = 3.15
Toluene	515 mg/l	22 mm Hg	Slow	Fathead Minnow TLm=56 mg/l Aquatic Toxicity Rating=100-10 ppm Rate Oral LD_{50}= 5,000 mg/kg Bacterial Inhibition at 29 mg/l	Log Poct – 2.69
Acrylonitrile	Miscible	100 mm Hg	Very Slow Inhibition of Pseudomonas at 53 mg/l	Fathead Minnow LC_{50} 18.1 mg/l Aquatic Toxicity Rating TLm96:100-10 mg/l Rat Oral LD_{50} 82 mg/kg Human Suspect Carcinogen	Log Kow = -0.92

Key to Abbreviations Used

NA = no information available

K_{ow} - octanol-water partition coefficient

ThOD   theoretical oxygen demand for complete oxidation to $CO_2 + H_2O$

BOD_5 5 day seeded biological oxygen demand

LD_{50} single dosage to test animal in mg/kg of body weight at which 50% mortality is observed in the test population

LC_{50}, or TLm96 = concentration of test chemical in water that will fill 50% of the exposed organisms within 96 hours

mmHg   pressure expressed in millimeters of mercury

Factors favoring offsite transport are a high vapor pressure and water solubility. Compounds with low water solubility will tend to favor adsorption to soil particles. Even at saturation in water solution, a compound with a low water solubility would represent a much lower release rate in a groundwater plume than a readily soluble material. Biodegradeability and reactivity are also important factors to cofnsider. A material which is slowly degraded by microbial processes can achieve a much higher effective concentration when compared to a compound released at a similar rate but rapidly biodegraded or not stable enough to exist in the toxicologically active form when released into the environment.

Table 1 is a list of site-specific indicator compounds formulated for a site which has been used for the disposal of polymer production wastes. The list was formulated from a set of over 75 compounds known to have been used or disposed of on the site. The compounds chosen as site specific indicators are moderately to highly toxic in acute exposures are some are known or suspect carcinogens. Many of the compounds are Priority Pollutants. The materials on the list are degraded slowly and are moderately to highly soluble in water, yet have K_{ow} values indicating that they would be bioaccumulated. They represent the compounds used or disposed of on site with the greatest potential for movement offsite to cause harm in exposed populations. The next step in the remedial inves-

tigation would be to collect samples of soil and groundwater at various locations on the site and perform analyses for the indicator chemicals.

BIOASSAYS

Another technique which is useful in evaluating the components of an uncontrolled waste site is the use of standard acute aquatic bioassays. Bioassays are rapidly becoming an accepted means of monitoring complex effluents. Many discharges under the National Pollutant Discharge Elimination System (NPDES) are currently required to perform aquatic bioassays as part of their discharge permits. The protocols developed can be easily adapted for the evaluation of leachates and groundwater flowing through a waste area.

The favorable aspects of the inclusion of aquatic bioassays in a remedial investigation are their ability to address the complex nature of a waste mixture and provide information on the end point of concern, namely toxicity. Whereas the toxicological evaluation which is undertaken during selection of indicator compounds considers one chemical at a time, the bioassay is a demonstration of the toxicity of the entire set of compounds present in a solution.

A set of components, all of which are present below a reported toxic threshold in a solution, may add up to a toxic dose, may act

synergistically to enhance the magnitude of the toxic response, or they may act to detoxify the mixture either by inhibitory or chemical means. Exposure assessments are usually conducted on one chemical at a time, relative to sometimes sketchy or sparse literature values. Bioassays can be used to monitor the actual toxicity of the waste mixture as it occurs at various points within a site.

Bioassays can also address those components which the analytical chemical survey or indicator parameter evaluation may have missed. In this respect, bioassays can be used as a mechanism for verifying risk estimates or acting as a fail-safe mechanism as well as investigating a waste site for which no information is available. A bioassay program can be designed which addresses the source and transport components of the risk assessment, and depending upon the type of test organisms used, can also function to model the responses of a specific receptor. The calculated result of the bioassay is a probability which can be reported as risk at various levels of exposure.

Table 2 presents the results of a battery of bioassays conducted using surface and groundwater collected from an uncontrolled waste site. There was a concern that materials leaving the site with groundwater were entering a nearby river and causing harm to aquatic life. Figure 2 is a diagram of the site and the sampling locations.

The bioassays utilized were a static acute 96-hour fathead minnow *(Pimephales promelas)* assay, a static acute 48-hour *Daphnia magna* bioassay and a static 120-hour algal inhibition bioassay using the green algae *Selenastrum capricornutum*. The bioassays were conducted in accordance with EPA-Level 1 protocols for the biological evaluation of complex affluents' and guidelines established by the New York State Department of Environmental Conservation.[6]

The bioassay organisms were chosen to represent aquatic life at three trophic levels. The green algae is a primary producer which fixes photosynthetic energy and provides food for higher trophic organisms. *Daphnia magna* is a small freshwater crustacean which grazes on plankton and algae, while the fathead minnow represents a predatory animal high in the aquatic food chain.

The minnow and Daphnia bioassays were conducted in triplicate at five levels of dilution using ten organisms per dilution. Dilution and control water were collected from the river, upstream of the
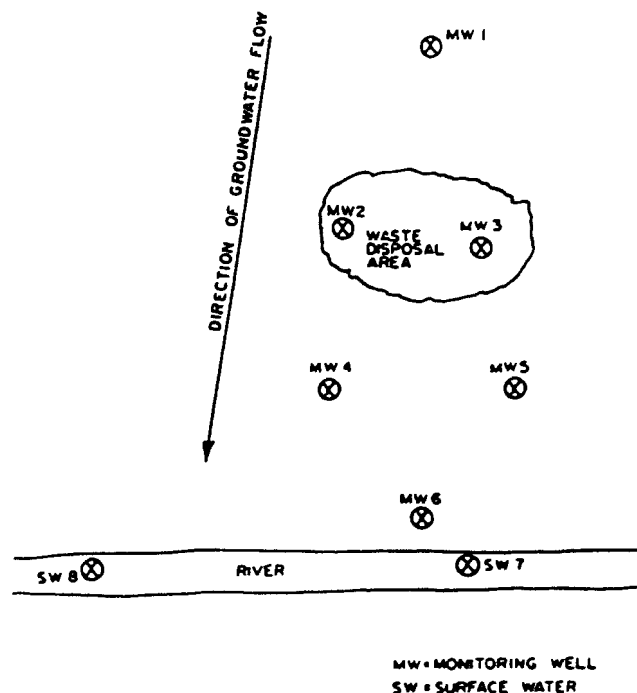
Figure 2
Diagram of Waste Disposal Area

area of the landfill. The groundwater samples were collected from shallow wells drilled into the uppermost, unconfined aquifer. Bioassays were initiated within 24-hours of sampling. The algal assay was conducted by seeding dilutions of samples in nutrient solution with algal cells from an actively growing culture.

The results of the bioassay indicate that groundwater collected from within the disposal area is acutely toxic to aquatic life. The dilution LC_{50} value corresponds to the concentration of sample in dilution water at which 50% of the exposed test population is killed. Undiluted groundwater from within the disposal site killed

Table 2
Results of Aquatic Bioassays

| Site | Location | Fathead Minnow | | Daphnia Magna | | Selenastrum Capricornutum |
		Survival in 100 % Sample	Dilution LC50	Survival in 100% Sample	Dilution LC50	50% Inhibition Level
1	Upgradient Well	*10/10	>100%	10/10	>100%	None
2	Well in Waste Area	0/10	2	0/10	4	24%
3	Well in Waste Area	0/10	8	0/10	7	37%
4	Well 200' Downgradient	9/10	>100%	6/10	>100%	None
5	Well 200' Downgradient	7/10	>100%	8/10	>100%	None
6	Well 400' Downgradient	10/10	>100%	10/10	>100%	None
7	Downstream Surface Water	10/10	>100%	10/10	>100%	None
8	Upstream Control	10/10	>100%	10/10	>100%	None

*
10/10 = number of survivors/number at start of test
LC_{50} = concentration of sample in dilution water at which 50% mortality occurs.

all of the exposed minnows and Daphnia. The dilution LC_{50} values for water from within the site are less than 10%. Groundwaters with dilution LC_{50} values of less than 10% are considered highly toxic. The algal bioassays of water from sampling sites 2 and 3 were also determined to be inhibitory to the growth of algae. Inhibition of the growth of algae by 50% was calculated to occur in a solution containing 24% of groundwater from site 2 in nutrient medium and 37% at site 3. No significant inhibition of algal growth was observed at any of the other sites.

The bioassay results of samples collected at the upgradient site and most of the downgradient wells did not reveal any major toxicity. Wells 4 and 5, situated approximately 200 feet downgradient to the disposal area, displayed toxicity in the 100% groundwater samples. The dilution LC_{50} values of >100% indicate that a 100% solution of groundwater could not induce a 50% mortality in the test populations. Nevertheless, mortality as high as 40% was recorded in Daphnia at site 3.

CONCLUSIONS

It can be concluded from the bioassays that wastes in the disposal area contain components which are toxic to aquatic life. The results indicate that some of the toxic components may be leaching out of the disposal area and transported by the movement of groundwater. However, samples collected from wells further downgradient or from surface water collected at the river indicate that acute impacts are not being experienced offsite.

SUMMARY

This paper presents two approaches to the generation of data for use in remedial investigations of uncontrolled hazardous waste sites. Both methods are designed to provide information independent of analytical chemical determinations and attempt to integrate the source and transport elements of a risk assessment. A distinction is made between hazard and risk because of the dangers of concluding that a risk exists based on a single hazard term, such as toxicity, without evaluating mechanisms for exposure or the existence of receptors.

The site-specific indicator parameter scheme outlined is a promising technique which focuses on those chemicals which can be the source of risk to exposed populations. It allows chemical analyses to be geared toward a specific set of chemical compounds by

methods which can be devised to provide acceptable, defensible levels of analytical precision and accuracy. However, the site specific parameter scheme relies heavily on existing information. Its use is limited to those instances where adequate information on site operations and a cooperative responsible party is available. Its utility dissolves for sites where little information is available on the nature of activity or wastes.

The bioassay technique described is a rapid, relatively inexpensive method for evaluating toxicity. It is well suited for the evaluation of complex mixtures. Used in conjunction with an analytical survey for site specific indicator parameters, as well as some generic assays such as Total Organic Carbon, bioassays can function as a double check for detecting unidentified toxic components. They can also function as an indication of site risks.

The bioassays presented suffer from the inability to provide information on chronic toxicity. At the present time, most aquatic bioassays of chronic toxicity are much more difficult to perform than the statis acute bioassay. However, these assays can be carried out where necessary, and simpler techniques are currently being developed. The aquatic bioassays also are not suitable for the estimation of toxicity to humans. However, bioassays can be devised using small mammals as well as microbial or cell culture assays which can be used to estimate risks of injury to humans.

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THE IMPORTANCE OF THE ENDANGERMENT ASSESSMENT IN SUPERFUND FEASIBILITY STUDIES

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INTRODUCTION

The investigation, assessment and eventual solution of problems at uncontrolled hazardous waste sites has evolved in the years since the passage of CERCLA into a set of prescribed steps based upon the National Contingency Plan and leading to cost-effective, feasible and environmentally sound removal of actual and potential threats to human health, welfare and the environment. One of the most important steps toward hazardous waste site remedial action is the Endangerment Assessment, a relatively new concept in Superfund actions.

The Endangerment Assessment combines site evaluation, chemical fate and transport evaluation, basic toxicology and risk and exposure assessment into a description and quantification of actual and potential hazards and risks associated with the site. The Endangerment Assessment requires a multidisciplinary effort. The lead role is carried by the environmental toxicologist with close cooperation from the hydrogeologist, chemist and engineer. The stated purpose of the Assessment is to determine where remedial action is required at a site to mitigate actual or potential threats to human health, welfare or the environment and to access the level to which site cleanup is required.

A preliminary Endangerment Assessment should be conducted at all hazardous waste sites in general, and NPL sites in particular, at the initiation of the Remedial Investigation in order to focus the data collection efforts. The final Endangerment Assessment, which is developed after the Remedial Investigation is completed, is a bridge between the Remedial Investigation and Feasibility Study and establishes the objectives of the latter.

The Endangerment Assessment must characterize a hazardous waste site thoroughly in terms of contaminant source, pathways and receptors. The source characterization will define the hazards (i.e., chemicals) associated with the site; characterizations of pathways and receptors define the exposure. Assessment of both hazards and exposure leads to the description and quantification of risks. It is important that the Endangerment Assessment considers both hazards and exposure to deliver to the remedial engineer a reasonable and reliable representation of the types and degrees of threats posed by the site.

Source characterizations are as varied as the hazardous waste sites themselves. The Endangerment Assessment team must carefully review all data available in order to assess the character of the site and the chemicals present. Pathways usually are limited to four media: air, water surface, groundwater and soil, but other media, i.e., fish, game, crops, etc., may be important at certain sites. Receptors must be identified for each site based on the pathways and area demography.

SOURCE CHARACTERIZATION

To characterize the source, the Endangerment Assessment utilizes information available through previous investigations to describe the site location, appearance, topography, geology, hydrology and history. In addition, it describes the chemical and physical properties of the contaminants detected at that site in terms of the potential for those pollutants to be released from the site to the air, groundwater, surface water or soil and to contribute to endangerment of area populations, including sensitive populations, wildlife and/or the environment.

As part of the data review for the Endangerment Assessment, all hazardous substances detected in air, groundwater and surface water, soils, sediments and waste at the site are identified. These data are more easily managed if they are categorized by the environmental media in which they were found. The physical and chemical properties of the chemicals are reviewed, including molecular weight, chemical formula, vapor pressure, water solubility, solubility in other solvents, biologic detection limits (taste and/or odor) in air and water, bioconcentration factors, soil/sediment adsorption coefficients, octanol/water partition coefficients, melting and boiling points, degradation rates in water, soil and in biological media, analogous compounds on the basis of structure-activity relationships and other factors that may affect the substance's behavior in the environment.

When several chemicals of the same type are present at a site in similar concentrations, they may be treated together in the Endangerment Assessment if they have similar toxicological properties. Chemicals with similar structures often behave similarly in the environment and have similar toxicities. The table(s) developed as part of the description of the chemical and physical properties can be used to compare properties of chemicals and to assess their potential environmental behavior.

Toxicology Assessment

Following identification of chemical hazards present at a site, each chemical or chemical class is assessed to determine its toxicity to people and wildlife.

The profiles are the result of literature searches to identify relevant toxicity data, epidemiological studies and clinical case studies. Since extrapolations from test animal to population of concern and dose (usually high to low) are almost always required, uncertainty is introduced. Topics and data considered in hazard assessment include:

• *Pharmacokinetic Properties*

The four pharmacokinetic processes of adsorption, distribution (and storage), metabolism (transformation) and excretion are re-

viewed for each chemical. These processes describe the mechanisms by which people may be exposed to a chemical, and how it behaves chemically once it is absorbed into a living organism. The pharmacokinetics of a chemical will influence its toxicity.

•*Acute Toxicity*

Information about human, laboratory animal and aquatic life acute toxic effects (LD_{50}'s, etc.) of a chemical are presented. This information enables one to make comparisons between chemicals in terms of relative toxicity. Organ systems affected will also be noted. Human data are reported where available.

•*Subacute and Subchronic Toxicity*

Results of short-term toxicity studies are also reported. These studies give a better assessment of the target organs of a chemical than acute studies that generally expose an animal to a single high dose of a chemical.

•*Chronic Toxicity*

Results of long-term studies in laboratory animals are described along with reports of long-term human exposures, as in occupational settings.

•*Epidemiology*

Epidemiological studies of the chemicals under review are studied. These studies provide the best assessment of potential human effects of chemicals.

•*Clinical Studies and Case Reports*

These studies, although not always as complete as epidemiological studies, provide excellent information on effects of chemicals on people. Clinical studies are controlled exposures of volunteers to chemicals, usually at low levels. They provide insight into organs affected by exposures and levels of chemicals at which effects occur. Case studies provide information on single cases of uncontrolled chemical exposure, often to high levels. These exposures are generally accidental or occupational.

•*Mutagenicity*

Chemicals that are mutagenic in bacteria or mammalian cell culture are often carcinogenic in laboratory animals. This information is important in evaluating the effects of hazardous chemicals.

•*Teratogenicity*

Effects of chemicals on unborn organisms is evaluated. Human data are included where available.

•*Carcinogenicity*

Although toxic (noncarcinogenic) effects are critically important in identifying chemical hazards, carcinogenic effects generally cause the most concern among the population at large. Carcinogenicity data are reviewed thoroughly to assess potential carcinogenic risks resulting from a site.

PATHWAY AND RECEPTOR CHARACTERIZATION

The preceding exercises permit the identification and characterization of a hazardous waste site and the chemical hazards associated with it. In order to be of use to the engineer coordinating the feasibility study, the information gathered and assessed concerning the site must be screened and analyzed to direct remedial action properly.

Two fundamental questions must be answered: who is exposed, and to how much? The answers are achieved through pathway and receptor identification and assessment. The information that was presented in the physical and chemical properties tables is half of the basis of the pathway characterization and resulting exposure assessment. The other half is the assessment of physical, topographical, geological and hydrological features of the site.

The assessment of physical and chemical properties of substances found at the site permits evaluation of the potential for each chemical to migrate within, between and among environmental media; the site characterization identifies these pathways of exposure that are most critical for the site. Routes of exposure (pathways) are defined by evaluating each possible migration pathway in terms of populations and/or environments near or distant from the site that may be affected via that pathway. The following factors that must be addressed are:

Demography

The Endangerment Assessment evaluates the number of people possibly affected by the site, the distance and direction from the site in which they live and the source(s) of their drinking water. The demographic evaluation includes people who live, work, play, shop or go to school near the site.

Environmental Description

Because things other than people are also affected by hazardous waste sites, the Endangerment Assessment looks at ecological habitats near the site. Plants, animals and microorganisms excepted in the site area are described, with special emphasis on unique ecosystems and threatened or endangered species. Where specific plant and animal habitats are not known, assumptions of types of organisms living in an area can be made based on the type of environment and the geographic area.

Topography and Hydrography

A thorough description of surface land and water features enables an assessment of direction and effects of overland flow and runoff to be made for a site. These pathways are critical, especially if surface water is a source of potable water in the area or if surface water is used for recreation. Surface water is also a pathway for exposure to fish which are consumed by people and wildlife and to crops via irrigation.

Meteorology and Climate

Knowledge of prevailing meteorological conditions at a site enables a description of populations potentially at risk of exposure to airborne contaminants. The most important information is prevailing wind direction and average wind speed. If possible, monthly and/or seasonal wind roses are obtained or can be generated if sufficient data are available. This information is used to assess whether the air route is important as a means of exposure in a given area.

Geology and Soils

A description of soil and rock types underlying the site is important for evaluation of migration or stabilization of chemicals in the porous media. Fractured bedrock or permeable soils and rock are often critical pathways for transmission of contaminants from hazardous waste sites.

Hydrology

Hydrological and hydrogeological data provide information to assess migration of chemicals from the site in groundwater. Exposure through drinking water may be one of the most important routes of exposure associated with a CERCLA site. Relationships between surface and groundwater are assessed in order to further define routes of migration and relationships between environmental media.

This information is used to determine where exposures to contaminants from a site may occur. Air, surface water or groundwater modeling are often required to assess who the receptors are and to what levels of chemicals they may potentially be exposed. The following routes of exposure are commonly evaluated:

Air

Humans can be exposed to airborne contaminants due to the volatilization of chemicals from the soil surface or from the surface of leachate or bodies of water such as wetland areas or streams. Another source of airborne exposure is dust generated by wind or activities on a site. People at risk of exposure to airborne contamination will be those living downwind from points of discharge to air. Through use of wind rose data, the percentage of time during which specific populations can be at risk of exposure can be calculated. Airborne contaminants can also contribute to surface water, soil or vegetation contamination when they settle out or are washed out of the atmosphere. The interrelationships of air and other media are assessed for each site depending upon site-specific characteristics.

Surface Water

Humans can be exposed to contaminants in surface water by drinking the water or by contact with it. Uses of air surface waters are explored to assess whether waters near a site are used for drinking or human contact.

Groundwater

Groundwater used as drinking water can be a route of exposure at many sites. Uses of groundwater in the vicinity of each site will be reviewed to determine whether people can be exposed through this route. Interrelationships between surface and groundwater are evaluated.

Direct Contact

Contact with contaminated soils or exposed wastes on a site may be a significant route of exposure, especially if people or animals can easily gain access to the site.

Ingestion of Contaminated Fish

People who eat fish that have been exposed to contaminated surface water, sediments or organisms can be exposed in this manner. Humans who live far from a site may be exposed if commercial fisheries or widely used sport fishing areas are involved. The Endangerment Assessment evaluates use of fish from streams and lakes downstream from hazardous waste sites.

Ingestion of Contaminated Plants or Animals/Birds

Wild or domestic animals and birds used as human food become contaminated if their food or water supplies are contaminated. People may also be exposed to food crops contaminated by exposure to chemicals in surface water, groundwater or air. In all cases of fish, bird, land animal or crop contamination, evaluation of uptake and bioconcentration factors is important.

RISK

After routes of exposure are identified and evaluated, risk assessment must be conducted to further identify those routes of exposure that contribute significant threats to human health, welfare or the environment. The risk assessment conducted as part of the Endangerment Assessment is a screening process to determine the goals of remedial action. The risk assessment integrates exposure and hazard to identify baseline threats at the site. The engineer addresses these threats and, in the feasibility study, addresses the means by which these threats can be mitigated.

Risk assessments may be quantitative or qualitative. Quantitative assessments can be made for substances and routes of exposure for which sufficient information is available. Qualitative assessments are made when there is more limited information and when specific effects, such as carcinogenicity, can be related to exposure but levels of exposure causing those effects cannot be evaluated.

In GCA's risk assessment approach, human health criteria and evaluations developed by the U.S. Food and Drug Administration, USEPA, World Health Organization and other scientific bodies are used to evaluate human health effects from hazardous waste sites.

Data are likely to be presented in terms of No-Observable Adverse Effect Levels (NOAELs) for noncarcinogenic effects; a safety factor is applied to these data to derive the Acceptable Daily Intake (ADI) for humans. Carcinogenic compounds often are not examined for other chronic effects, since those other effects generally result from high exposures than those that cause carcinogenic effects. A generally acknowledged exception is teratogenicity, which cannot be predicted quantitatively.

Noncarcinogenic effects generally are exhibited only after exposure has reached a threshold; lower exposure will cause no effect, and higher exposure is assumed to always elicit the response. The threshold is determined by animal testing; that value is converted to what is essentially considered to be the human threshold, the ADI.

The range of exposures to each pollutant is compared to the ADI for that pollutant if one exists. Exposures exceeding that ADI will be assumed to be capable of causing the health effect.

An exposed individual's probability of developing cancer from ingesting contaminated fish can be predicted for many of the pollutants of interest. The USEPA Carcinogenic Assessment Group (CAG) has developed risk scores in $(mg/kg/day)^{-1}$ for many pollutants suspected to be human carcinogens based upon animal studies. The exposures calculated for average and highly exposed persons are multiplied by the unit risk scores; the result is that per-

son's lifetime probability of developing cancer from exposure via that route.

Risk assessments addressing environmental degradation other than adverse human health effects are also possible. Generally, the data base and the overall understanding of the exposure and the exposed population are not as complete as for human risk assessment. Therefore, reliable quantitative environmental assessments are infrequent. The procedure for evaluating environmental threats is similar to that for assessing human health effects; the data reviewed and the endpoints selected for evaluation are those that affect wildlife, biota, benthic organisms, etc.

Human welfare issues are more difficult to evaluate and remediate. Issues such as decreased property values, loss of natural resources, loss of development potential in an area and emotional stress associated with living near a hazardous waste site should also be considered in the Endangerment Assessment.

CONCEPTUAL REMEDIAL OPTIONS

At sites requiring a full Remedial Investigation and Feasibility Study, an engineer will rely on the results of a preliminary Endangerment Assessment, conducted at the initiation of Remedial Investigation, to develop a detailed scope of work for the field effort. The preliminary assessment will clearly define data needed to assess the nature and extent of the problem. The preliminary exposure and hazard assessments are important to the development of conceptual remedial options which may be applicable to the site.

The preliminary exposure assessment will identify the contaminant pathways posing important threats to area receptors. This assessment will aid the engineer in determining what environmental media must be addressed and the general locations for remedial actions. The engineer can then develop a list of conceptual remedial options such as:

- Excavate contaminated soils at source, treat and dispose on-site
- Recover contaminated groundwater, treat and discharge to surface water
- Provide alternative water supply
- Provide permanent site security
- Install a groundwater barrier wall

For each conceptual option, a list of preliminary remedial technologies can be developed. For the soil excavation and treatment option presented above, preliminary technologies might include:

- Soil excavation
- Dust control
- Biological treatment
- Incineration
- Waste stabilization
- Disposal in on-site RCRA-approved landfill

The preliminary hazard assessment will identify the types of chemicals at the source and how they have been released. It will also identify those compounds, due to their mobility and toxicity, which pose the greatest threat to public health and the environment and, therefore, which must be given highest priority during site remediation. The engineer will use this information to screen the preliminary technologies, in particular, those which address treatment (e.g., a strictly heavy metals problem would preclude the use of biological treatment).

The engineer undertaking the investigation must identify preliminary technologies before going into the field to collect data. With a manageable number of technologies in mind, the engineer can design a sampling and analysis program to collect engineering data necessary to evaluate the appropriateness of each. This approach reduces the need for costly and time consuming returns to the field during the Feasibility Study phase of the project.

IDENTIFICATION OF REMEDIAL ALTERNATIVES

The final Endangerment Assessment is conducted at the completion of the data collection effort. The final exposure and hazard assessments can be used by the engineer to refine the list of conceptual remedial options and to further screen remedial technologies for applicability to the site problem.

The most important step in the Feasibility Study process is the establishment of response objectives. Each project will have many objectives. In particular, the engineer must address a number of "institutional" issues such as compliance with RCRA, TSCA, OSHA and other Federal, State and local regulations. However, at the core of each remedial action is the need to mitigate the threat to public health, welfare and the environment as specified by the NCP. It is the Endangerment Assessment which defines these threats and answers the question of how clean is clean as specifically as the data base will permit.

The engineer should not always expect an exact set of target concentration levels for each contaminated media. That level of detail is normally beyond the capability of most Endangerment Assessments since neither the site data base nor the existing toxicology research base is sufficiently detailed. This is particularly true for human exposure to noncarcinogens and for environmental exposure. The engineer should typically expect a qualitative analysis of health and environmental threats and a clear presentation of their priority. That information can then be used to generate a set of site specific objectives for the response. Examples include:

• To the extent practicable, remediation must prevent direct human/animal contact exposure to the contaminated soils in specific areas
• Remediation must preclude the human consumption of groundwater containing contaminants above concentrations established based on toxicity
• To the extent practicable, remediation should minimize erosion of contaminated site soils and runoff to surface water

Note that the last objectives may mitigate effects on biota, namely fish, in the stream. However, if human consumption of contaminated fish is also an important exposure route, then halting fish consumption would be an additional response objective.

After the response objectives and some site-specific design criteria have been established, the engineer can combine applicable remedial technologies into specific remedial alternatives which must then be screened to eliminate those that are clearly too costly for the reduction in threat provided.

EVALUATION OF ALTERNATIVES

Two important elements of the detailed evaluation of remedial alternatives are the public health analysis and the environmental analysis. These are conducted in conjunction with technical, cost and institutional analyses.

The purpose of the public health analysis is to evaluate the reduction or, in some cases, increase in threat to public health as a result of the implementation of each remedial alternative. The baseline or "no action" threat is that established by the Endangerment Assessment. The analysis can be either quantitative or qualitative, depending upon the types of contaminants and/or the extent of the data base.

The purpose of the environmental analysis is to evaluate reduction or increase in threat to biota from remedial alternative implementation. Since the toxicology research base is limited, this analysis will be qualitative. Again, the baseline threat is that established by the Endangerment Assessment.

Ultimately, the selected remedial alternative will be that which is technically reliable, satisfies institutional criteria (including public welfare concerns) and cost-effectively mitigates threats to public health and the environment. At any hazardous waste site where cleanup funds are limited (there are very few outside of this category), remedial action must be prioritized and funds allocated to mitigate threat to public health first and threat to the environment second. It is clear that the engineer must rely heavily on the expertise of the environmental toxicologist and must thoroughly understand, and be able to contribute to, the site remediation tool known as the Endangerment Assessment.

HEALTH RISK ASSESSMENTS FOR CONTAMINATED SOILS

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INTRODUCTION

Hazardous waste contaminants are known to partition between environmental media based on their physical and chemical properties.[1,2] Both metals and organic contaminants tend to sorb to a greater or lesser degree onto organic matter and clay particles in the soil and sediment.[1,3] Consequently, soils serve as a sink for many contaminants, particularly cationic metals and the organic compounds with low water solubility and high sorption coefficients.

Of the various pathways of exposure associated with hazardous waste sites, the soil pathways are among the most important but least understood. Exposure from contaminated soils can arise from inhalation of dust, incidental ingestion via soiled hands, bioaccumulation by crops and livestock and leaching into surface or groundwaters used for drinking. Experience has indicated that exposure via incidental soil ingestion may be the critical pathway at many sites.

One of the difficulties in evaluating health risk from contaminated soils is the general lack of health criteria for the soil medium. Unlike the air and water media, health specialists have no convenient criteria to serve as a basis for comparison. To be sure, the USEPA has established criteria for land application of sewage sludge to land,[4] and agronomists have also established general guidance on tolerable levels of soil contamination for agriculture.[5] However, these criteria are more appropriate in evaluating soil bioaccumulation or crop and animal toxicity potential.

A simple, reliable method of deriving soil criteria based on incidental soil ingestion is needed for determining the health risk of contaminated soils in or near residential areas. Public health specialists have many years of experience in evaluating the relationship between the pica habit of soil ingestion and urban childhood lead poisoning.[6] Similar studies have indicated that, for heavy metal exposure around smelters, the soil ingestion pathway may be the most critical exposure pathway.[7]

Until recently, a troubling aspect of this approach was that not enough was known about the amount of soil actually ingested by children. More research is required on this subject. However, the Centers for Disease Control of the U.S. Public Health Service has established soil ingestion figures for various age groups of the population (Table 1).[8] In this paper, the author discusses a method devised to utilize these soil ingestion data and certain health criteria to calculate health-related soil criteria.

METHODS

Two separate types of contaminants are commonly encountered at hazardous waste sites: those substances which at small, subthreshold doses are not thought to cause any chronic health effect, and those substances which at low doses pose a small but finite cancer risk. Separate methods are presented for each type of contaminant.

Threshold Contaminants

A health criterion should be designed to protect the most sensitive fraction of the population. Table 1 shows that the age group 1.5 to 3.5 years consumes a disproport.nate amount of soil. Given their low body weight compared to an adult, in addition to their soil ingestion habits, children in this age group are clearly at greatest risk of exposure from contaminated soils at hazardous waste sites. A daily soil ingestion figure of 10 g/day appears to be the proper level to consider when evaluating worst case exposure.

The most useful health criterion for threshold contaminants is the allowable daily intake (ADI). This intake, usually expressed in terms of mg/day, was originally devised by the FAO/WHO Expert Committee on Food Additives.[9] It was intended to be the adult intake at which it was believed no lifetime health effects would occur; however, it was not intended as a guarantee of absolute safety.

The ADI may be modified by body weight and daily soil intake to calculate the soil criteria (SC). A 10 kg bodyweight and a 10 g/day soil intake are used to provide protection for the most exposed group. The method of calculation is as follows:

$$SC \; (ug/g) = ADI \; (mg/day) \times 1000g/kg / SI \; (g/day) \times BW \qquad (1)$$

where SI is the soil ingestion (10 g/day) and BW is bodyweight adjustment (10 kg/70 kg). Using phenol as an example, the ADI is 7.0 mg/day,[10] the soil criteria derived according to this method is 100 mg/kg (ppm).

Carcinogens

The child soil ingestion figure of 10 g/day is not appropriate for exposure to carcinogens since it is a figure assigned for a very limited age group and does not reflect the lifetime soil ingestion exposure. Cancer risk is considered to be cumulative over a lifetime, hence soil exposure should also be evaluated in cumulative fashion. A lifetime average soil ingestion (LASI) of 0.006 g/kg/day was calculated from the data in Table 1. This figure was obtained by summing the lifetime soil ingestion and dividing by 70 kg bodyweight and by the days in a 70 yr lifetime. A slightly higher soil ingestion figure could be obtained by using a lifetime average bodyweight.

Since lifetime exposure is the concern with carcinogens, some allowance should be made for the degradation of the contaminant in the soil over the human lifetime. The environmental half-life of the contaminant may be used to account for the fate processes

Table 1
Soil Ingestion by Age Group, Calculation of Lifetime Average Soil Ingestion (LASI)

Age Group	Years	Ingestion (g/day)[7]	Sum of Soil Ingestion (g)
0-9 mos	0.75	0	0
9-18 mos	0.75	1	274
1.5-3.5 yrs	2.0	10	7300
3.5-5 yrs	1.5	1	548
5-18 yrs	13.0	0.1	475
18 yrs	52.0	0.1	1898
			10495 g/lifetime
	1	lifetime	

10495 g/lifetime x 70 kg x 365 days x 70 yrs = 0.006 g/kg/d (LASI)

such as biodegradation, hydrolysis and photolysis. Of these processes, biodegradation data may be the most available.[11] A half-life adjustment factor of t/2/70 is applied to the calculation of the soil criteria, where t/2 is half-life in years and 70 is the approximate human lifespan in years. Half-life data generally assume linear decay. No half-life correction is applied to metals because they are resistant to degradation.

The health criteria may be obtained from slope estimates (also called unit carcinogenic risks, UCRs) published by the USEPA Carcinogen Assessment Group.[12] These data are expressed as an excess cancer risk from a lifetime of ingestion of 1 mg/kg/day of a carcinogen. By selecting an appropriate risk level, a figure loosely termed the "lifetime allowable daily intake" (LADI) may be calculated:

$$LADI \ (mg/kg/day) = Risk/UCR \qquad (2)$$

For example, the UCR for dieldrin is 30.4/mg/kg/day. At a risk level of $1x10-6$ (1 excess case in 1,000,000 exposed), the LADI is calculated to be $3.3x10-8$ mg/kg/day. The soil criterion is then calculated as follows:

$$SC = LADI \ x \ 1000g/kg/LASI \ x \ t/2/70 \qquad (3)$$

where SC = soil criterion (mg/kg), LADI = lifetime allowable daily intake (mg/kg/day), LASI = lifetime average soil intake (g/kg/day) and t/2/70 is the half-life correction factor. For example, the soil criterion for dieldrin, with a half-life of 0.14 yr, is calculated as follows:

$$SC = 3.3x10-8 \ x \ 1000/0.006 \ x \ 0.14/70 \qquad (4)$$
$$SC = 2.75 \ mg/kg \ (ppm)$$

Using DDT, with a UCR of 8.42, the LADI is $1.19x10^{-7}$ and the half-life is 14.6 yr. The soil criterion is calculated to be 0.1 mg/kg. Much of the difference is due to the half-life correction factor. As this term approaches unity, the soil criterion decreases. Arsenic, with a UCR of 15, a LADI of $6.67x10^{-8}$ mg/Kg/day and no half-life correction, has a soil criterion of 0.01 mg/kg.

DISCUSSION

With a global median soil concentration of 6 ppm,[13] arsenic is an example of a soil criterion derived by this procedure that is less than natural background levels. While there is no assurance that background levels are not contributing to local cancer incidence, it does not seem reasonable to establish a criterion that is more stringent than natural background levels. Therefore, the recommended guidance for naturally occurring metals is to accept the calculated criterion or background concentration, whichever is greater.

The soil criterion derived for carcinogens is based on some level of "acceptable" cancer risk. While no consensus has emerged on an acceptable level of risk, a risk of $1x10^{-6}$ is useful for a first approximation of a soil criterion.

Some doubt exists about the applicability of the half-life correction factor to threshold contaminants. The soil ingestion figure of 10 g/day is based on an exposure of only 2 yr (Table 1), and it is believed that degradation may not be substantial enough in that time period to warrant its use. Furthermore, the ADI was not originally intended for substances such as heavy metals which exert a cumulative effect in the body and are not subject to decomposition.

Other soil exposure pathways, including inhalation of wind-blown dust and crop and livestock bioaccumulation, are not directly addressed by this procedure. Limited experience with the extremely insoluble 1, 3, 7, 8 tetrachlorodibenzo-p-dioxin suggests that the exposure and cancer risk from soil ingestion exceeds exposure from food chain bioaccumulation.[8] In addition, several investigators studying lead exposure around smelter sites have reported that soil ingestion leads to greater exposure than dust inhalation.[7] Hence, it appears that establishing a soil criterion based on ingestion may provide an adequate margin of safety for other soil-associated exposure pathways.

The soil criteria derived by this procedure appear to provide health-based criteria that may be used to assess the health risk of soil exposure by direct contact and may also provide an adequate margin of safety for other soil pathways. These criteria may be used as a first approximation of cleanup levels for remedial action planning at hazardous waste sites. Other considerations such as future land use and other soil exposure pathways may influence final criteria selection.

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PUBLIC HEALTH SIGNIFICANCE OF HAZARDOUS WASTE SITES

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CENTERS FOR DISEASE CONTROL'S INVOLVEMENT

With the passage of CERCLA, funds have become available to identify, investigate and cleanup abandoned waste sites containing hazardous substances, pollutants or contaminants and to provide immediate response to environmental emergencies involving hazardous substances. This Act provides a national response mechanism to protect public health, welfare and the environment from any releases or substantial threat of releases of any pollutant or contaminant that may pose an imminent and substantial danger.

CERCLA defines pollutants or contaminants as elements, substances, compounds or mixtures, including disease-causing agents, which, after release into the environment and upon exposure, will or could cause death, disease, behavioral abnormalities, cancer, genetic mutation, physiological malfunctions (including reproductive pathologies) or physical deformities in organisms or their offspring. The definition does not include petroleum or natural and synthetic gas.

The role of the Department of Health and Human Services (HHS) under CERCLA is defined in both Executive Order 12316, "Responses to Environmental Damage," and the National Oil and Hazardous Contingency Plan [Title 40 *CFR* 300]. The President has delegated all authorities under Section 104 [b] of CERCLA relating to "illness, disease, or complaints thereof" to the Secretary of DHHS, who has further delegated these authorities to the Public Health Service/Centers for Disease Control (PHS/CDC). Whenever the PHS "has reason to believe that....illness, disease, or complaints thereof may be attributable to exposure to a hazardous substance, pollutant, or contaminant, and that a release may have occurred or may be occurring," investigations and information gathering as determined necessary may be undertaken "to identify the existence and extent of the release or threat thereof, the source and nature of the hazardous substances, pollutants, or contaminants involved and the extent of danger to the public health...." Because of CERCLA and an agreement between the USEPA and PHS/CDC, the question of whether a site poses an imminent and substantial danger or threat to local public health is assessed for each site. The USEPA uses public health assessment and evaluation to help determine the priority that should be given to a particular site for remedial action. A site may require both immediate and long term remedial measures to safeguard public health.

CERCLA further stipulates that the Administrator of the Agency for Toxic Substances and Disease Registry (ATSDR), James O. Mason, M.D., who is also the Director of CDC, shall "in cases of public health emergencies caused or believed to be caused by exposure to toxic substances, provide medical care and testing to exposed individuals, including but not limited to tissue sampling, chromosomal testing, epidemiological studies, or any other assistance appropriate under the circumstances...." [Section 104 [i] of CERCLA]. CERCLA requires the newly created ATSDR to establish and maintain a:

- National registry of severe diseases and illnesses and of persons exposed to toxic substances
- National inventory of research information on health effects of toxic substances
- National list of all areas closed to the public or otherwise restricted in use because of contamination by a toxic substance

ATSDR also conducts periodic surveys and screening programs to determine relationships between toxic substance exposures and illnesses. Its medical epidemiologists and laboratory scientists are involved in a number of these screening and health effect studies at several Superfund sites. Some of these studues are outlined below.

STUDY	SYNOPSIS/STATUS
1. Battle Creek, MI, Health Study	Study to assess health effects of low levels of volatile organic compounds [VOC] in drinking water
2. Hollywood Dump Site, Memphis, TN	Study to assess exposures and health effects from insecticides
3. Pocono Summit Site, PA	Possibility of conducting a case-control study of eosinophilic granuloma
4. McKin Dump Site, ME	Proposed study to assess health effects of contaminated drinking water
5. Dioxin, MO	Health study for Quail Run; Adipose Tissue Study; and Reproductive Outcomes Study are awaiting final approval; preparations have begun
6. Oak Ridge, TN	Study to assess mercury uptake through fish consumption and exposure to contaminated soil
7. PCB Study Bloomington, IN	Study to assess PCBs
8. Childhood Lead Study, ID	Study to assess blood lead levels and lead levels in soils, house dust and vegetables due to a smelter; findings are indicating that increased blood lead levels are associated with high soil lead levels

9. Childhood Lead Study, East Helena, MT	Study to assess levels and environmental exposure pathways of lead, arsenic and cadmium; also analyzing 3-day composite stool samples for silicon, titanium and aluminum in order to estimate infant's dirt and dust ingestion
10. California Cooperative Agreement	Agreement to fund a number of studies in California, to include the BKK landfill and Silicon Valley groundwater contamination
11. Tacoma Smelter Study, WA	Study to examine environmental exposures to arsenic and subclinical health effects

ITEMS OF SIGNIFICANCE

To evaluate the public health significance of hazardous waste sites, State and local public health agencies, Federal agencies and environmental consulting firms involved in the assessment of hazardous waste sites require more resources to understand and determine the:
- Primary contaminants of concern
- Potential environmental pathways for exposure
- Potential health impacts from exposure
- Objectives of a public health evaluation
- Information necessary to adequately study the health implication of a hazardous waste site
- Prioritization of hazardous waste sites to assign environmental testing, remedial measures or health studies to a site because of the potential or known danger to public health

Effective decisions to protect public health can only be made if sufficient information is available on each hazardous waste site and the potentially affected local populations and environment. As one gains information about the potential health effects of toxic substances and the relationship between exposure and these health effects along with a better understanding of the transport and exposure pathways, public health evaluations of hazardous waste sites will improve.

PRIMARY CONTAMINANTS OF CONCERN

In conducting a public health evaluation of a hazardous waste site, scientists need to identify what contaminants of concern exist on the site. To classify whether a substance at a waste site is a contaminant of concern, scientists first need to determine if it meets CERCLA's definition of a pollutant or contaminant. Next, they need to find out about the occurrence of releases and the toxicity of the released substance. The quantity, concentration, reactivity, compatibility, environmental persistence and transport potential of the substance are other important factors needing consideration to determine whether a substance at a site is a contaminant of concern.

Occurrence of Releases

These contaminants may include substances from uncontained spills, releases of a substance and substances that are likely to be spilled or released because of the condition of their containment vessels or structures. If the substance were adequately contained and environmental transport and exposure were not likely, the substance would not be one of immediate concern.

Toxicity

The kind of environmental toxicities that a substance poses to people and other organisms needs to be considered. For many substances, acute toxicity data are available; additionally, longer term toxicity data may also be available. Toxicologic information about the oncogenic, teratogenic and mutagenic effects of a substance known to be or suspected of being a genotoxin may be available. Dose-response data about a substance can provide the toxicologic information needed to describe the likely occurrence of an acute or chronic effect or, in the case of carcinogens, a probability of risk that a cancer death or other disease may occur over a lifetime of exposure.

Toxicity ratings and/or data are provided by Sax[1] and the National Fire Protection Association.[2] Toxicity data are also available from the HHS's National Toxicology Program agencies (including the National Cancer Institute,[3] the National Institute of Environmental Sciences, the Food and Drug Administration, the National Institute for Occupational Safety and Health,[4,5] the National Library of Medicine,[6] USEPA's Office of Health Research,[7] USEPA's Office of Water Regulations and Standards,[8] USEPA's Office of Toxics Integration and the National Academy of Sciences/National Research Council.[9]

Quantities and Concentrations of the Substance

If the quantities and concentrations of the substance at the point of release are sufficient to cause harmful effects to man or food chain organisms, the substance would be considered a contaminant of concern. For substances that are highly toxic, even very small quantities and concentrations may pose an unacceptable risk to public health. If the substance can be, or is being, transported from the point of release, the concentrations represented at the sampled site of transport and the degree to which these concentrations adversely affect public health would help determine whether the substance is a primary contaminant of concern. These environmental concentrations may be compared with applicable standards, criteria and guidelines to assess their acceptability in terms of public health, welfare and the environment.

Environmental Persistence and Stability of the Substance

The persistence and stability of the substance at the waste site is an important consideration in determining whether the substance would be considered a contaminant of concern. A number of physical, chemical and biological processes may be important in affecting the degradation and/or distribution of a substance in the environment. In many cases, the fate processes are predictable and can be used to assess the short term and long term significance of the contaminant to public health.[10] These processes can degrade a contaminant into a relatively harmless state or product at a rate which reduces or eliminates the initial hazard posed on or off the site. Depending on the substance, the processes can also create or transform it into a more harmful state or product.

Highly persistent substances with the ability to bioaccumulate in the food chain are often classified as contaminants of concern, particularly if environmental transport is demonstrated. Even if the waste site contains low levels of these contaminants, their ability to persist in the environment and bioaccumulate in the food chain can cause them to exceed permissible levels in water and food over a period of time. The USEPA's National Oil and Hazardous Substances Contingency Plan[11] gives persistence ratings for many organic compounds.

The stability of a substance also depends on its reactivity, its compatibility with other substances in the waste site and its mobility through different environmental media. Substances can be highly reactive when subjected to certain physical conditions and when mixed with incompatible materials. Sudden releases of concentrated air pollutants may result. The NFPA assigns reactivity ratings to a number of common chemicals.[2] Chemical incompatibility can be determined by examining Table 12, "Incompatible Materials," in the National Oil and Hazardous Substances Contingency Plan.[11]

The mobility or transport of a substance depends on a variety of chemical, physical and biological processes. Aquatic fate processes depend upon several physiochemical factors for the substance, including vapor pressure, octanol/water partition coefficient, lipid solubility, aqueous solubility and local environmental conditions—pH, sunlight flux, ionic composition and strength of the water, redox potential, organism population and temperature. Chemical speciation, photolysis, oxidation, hydrolysis, volatilization, sorption, bioaccumulation and biotransformation are fate processes that can affect a substance's mobility. The USEPA has classified these aquatic fate processes for each of the 129 priority pollutants.[12] Examining the probable fate processes for the contaminants will help determine which contaminants on the site are of concern because of their predicted environmental behavior.

Fire and Explosive Hazards

If a waste site contains substances that are highly reactive, incompatible with other substances on the site or easily ignited, the potential safety hazards of fire and explosion to surveillance and monitoring teams and to cleanup crews and local populations must be evaluated before the site is disturbed in any way. The NFPA has classified ignitability, incompatibility and reactivity levels.[2] The U.S. Department of Transportation has developed evacuation tables[13] for different compounds for fire and explosive hazards and downwind air pollution hazards.

POTENTIAL ENVIRONMENTAL PATHWAYS FOR EXPOSURE

Human exposure to the primary contaminants of concern usually depends upon two pathways: transport pathways and exposure pathways. Transport pathways are the displacement of the contaminant from a source of contamination to a receptor site. Exposure pathways are avenues by which humans may absorb or react to contaminants through contact, ingestion or inhalation.

Even though contaminants can be transported from a source of contamination through a variety of different processes, health authorities need to determine and rank the significance of the transport routes in causing human exposure and endangering public health. Mitigation efforts should be concentrated on these routes until the imminent hazard from known or potential exposure is eliminated.

Transport Pathways

Hazardous materials can be transported from a waste or spill through several environmental pathways. Water, air, soil and sediment are the primary media of physical transport, whereas organisms in the food chain (both plant and animal) are the primary media for biological transport (Table 1). CDC has developed a screening procedure[14] for identifying the transport pathways and the factors associated with these pathways that in-crease the potential risk of exposure. When transport pathways cause human exposure to hazardous substances, the public health significance of the transport pathway depends upon the duration and degree of exposure, the health hazard posed by the contaminant of concern and the controllability of the transport or exposure pathway.

Site-specific information about environmental pathways is not always available. Therefore, environmental surveillance and monitoring of the site becomes necessary. Complete characterization of a site requires extensive field work and may be very expensive, yet still not provide conclusive evidence; the time required for study can delay implementation of interim measures to safeguard public health. Because of this, preliminary estimates of the concentration and the fate of the chemical in the local environment are often used to evaluate the hazards of the site, the possible duration of past exposures, the expected distribution and rate of contamination and the expected worst-case concentrations. These preliminary estimates can also be useful in determining the type and extent of additional environmental sampling required and the need for immediate protective measures.

Computer-based emergency response programs have been developed and are now available to serve as models for the dispersion of spills and contaminants in the environment. These computerized modeling programs can simulate the behavior of toxic clouds and plumes in both air and water and incorporate chemical source characteristics, hydrological and meteorological data and site-specific characteristics.

To estimate the fate of toxic substances in the aquatic environment, the USEPA, with the help of contractors, has developed screening procedures[15,16] for assessing the fate of toxic substances in both surface and subsurface water. Although these procedures have been verified with field data, users need to become aware of the assumptions, potential errors and limitations associated with them. The goal of these screening methodologies is to determine and identify, with a minimum of effort, whether either existing or projected loading rates from toxic pollutants are likely to reach hazardous levels in water resources. Aquatic fate predictions of

Table 1
Transport and Exposure Pathways

Transport Pathways / Contaminants In:	Occupational Mitigation Measures, Cleanup	Drinking Water	Swimming/ Bathing	Land/ Recreation	Air Quality Indoor	Air Quality Outdoor	Contaminated Food* Fish	Contaminated Food* Other Animals	Contaminated Food* Plants	Explosion Fire
Ground water	Inh,C	Ing	C,Ing,Inh		Inh					SH
Surface water	Inh,C	Ing	C,Ing,Inh			Inh	Ing	Ing	Ing	SH
Soil and Sediment	Inh,C	Ing	C,Ing,Inh	C,Ing,Inh		Inh,Ing	Ing	Ing	Ing	
Dust (Windborne or Man-Disturbed)	Inh,C,Ing	Ing		Ing,Inh	Inh,Ing	Inh,Ing		Ing	Ing	
Rainfall or Fallout	Ing	Ing				Inh,Ing	Ing	Ing	Ing	
Leaky Drums	Inh,C,Ing	Ing	C,Ing	C,Ing,Inh		Inh	Ing	Ing	Ing	SH
Other Contaminant Structures	Inh, C, Ing		C,Ing	C,Ing,Inh		Inh	Ing	Ing		SH

Probable Human Exposure Pathways:
Safety Hazard = SH; Ingestion = Ing; Skin and eye contact = C; Inhalation = Inh

*Food chain organisms contaminated through: direct contact; ingestion of contaminated organisms; soil or water; inhalation; habitation in contaminated water; and plant uptake of contaminants.

pollutants involve the delineation of the physical compartment of the environment within which the transport processes act and the identification of the pertinent fate processes:[15]

•Loading	—Inflow rates of toxicants (from discharge and from atmospheric, land runoff and sediment depositions)
•Speciation	—Acid-base Equilibria (pH)
	—Sorption
•Transport	—Precipitation/Dissolution
	—Advection (hydraulic flow)
	—Volatilization
	—Sedimentation
‡Transformation	—Biodegradation
	—Photolysis
	—Hydrolysis
	—Reduction/Oxidation
‡Bioaccumulation	—Bioconcentration
	—Biomagnification

To simplify the screening procedures and to minimize the effort that may be expended with a complete analysis of the fate of a toxicant, the USEPA[15] recommends that one should first assume that the pollutant behaves conservatively; that is, that it does not undergo reaction. This approach requires only data on pollutant loads and hydrological parameters rather than environmental data or rate constants. Since pollutant decay and removal processes are neglected, this approach will yield the highest possible estimate of pollutant levels.

If initial predictions are higher than a standard, a more refined approach, including the fate processes[12,13,15] and more complicated equations, would be necessary. If initial predictions are lower than a standard, a problem is unlikely. However, there are drawbacks to the conservative approach because it may neglect accumulations of the pollutant in other environmental compartments (that is, bedded sediments and any exposure that may result from these other compartments.

Exposure Pathways

If transport pathways or media are contaminated in excess of applicable standards, criteria or guidelines, adverse human exposure through ingestion, inhalation or contact could occur. When populations may be subject to adverse exposure, immediate efforts would be needed to identify necessary remedial measures. Possible transport pathways and media that could lead to human exposure are shown in Table 1.

POTENTIAL HEALTH IMPACTS FROM EXPOSURE

Without conducting a health study of the biological levels or health effects of populations with the greatest evidence or risk of exposure, researchers cannot obtain precise information on exposures and the resulting health effects. Potential risk and the magnitude of exposures can be estimated, however, by using risk assessments to approximate the public health significance of the exposure. Decision makers can use these estimates, along with information from relevant Federal and State guidelines, criteria and standards for hazardous substances in the various transport media, to assess the significance of the potential health impact and the imminency of the health hazard and to decide on the need for remedial actions. CDC has developed a screening manual,[14] *A System for Prevention, Assessment and Control of Exposures and Health Effects from Hazardous Sites* (S.P.A.C.E. for Health), to help States prevent, assess and control exposures and health effects from hazardous substances at these sites. These screening procedures will help State and local health agencies identify sites that need health studies. The purpose of the health studies are:
•To further assess the risk to human health posed by a given site so that appropriate preventive actions and public health measures

can be taken as needed and appropriate medical advice can be provided
•To advance scientific knowledge about the persistence and effects of hazardous substances in the body so that risk in other situations can be assessed

At many hazardous sites, health studies may not yield significant or meaningful results or may not be feasible. Therefore, it is particularly important to recognize circumstances in which health studies are likely to be useful and feasible.

OBJECTIVES OF A PUBLIC HEALTH EVALUATION

The primary objective of a public health evaluation is to address the questions posed by the requester. In addressing these questions, the public health official may need to appraise, investigate or identify the:
•Significance of each known environmental transport/media pathway (for example, groundwater, surface water, air, soil, sediment and food chain) as a cause of human exposure
•Significance of each exposure pathway (for example, ingestion, inhalation and body contact)
•Health effects that have already occurred or could occur from known exposure to the contaminants of concern
•Imminency of the health hazard via environmental exposure
•Imminency of the potential human health hazard via environmental transport
•The need for immediate actions to prevent, limit or mitigate an emergency situation because of the imminent risk or danger to public health
•The need for long term actions to prevent, limit or mitigate a potentially dangerous situation in the future
•The need for conducting epidemiological studies and for providing medical care and testing to persons exposed to toxic substances as a result of a public health emergency
•The health disorders and diseases that may be associated with exposure to a particular toxic substance; health disorders could include behavioral abnormalities, cancers, genetic mutations, physiological malfunctions, reproductive malfunctions and physical deformations including birth defects
•The need for reviewing and comparing local health data with regional, State or national data so that any statistically significant increases can be detected

NECESSARY INFORMATION

Public health officials must have specific information if they are to conduct a proper public health evaluation of a hazardous site. Reports for review need to be well organized and concise and they should include summary tables of the environmental data. When appropriate, these summary tables should be compared with applicable Federal and State standards, criteria and guidelines. Volumes of raw data should be included in a separate appendix, not in the report. The report should include:
•Characterization and a brief history of the site, adjacent land uses and identified health problems
•Name and approximate quantity of the contaminants of concern on-site and off-site
•Topographic, hydrologic and geologic descriptions, as well as maps of the site (aerial photographs can be helpful)
•A description of the accessibility of the contaminated zones on-site or off-site to human use and the land use (for example, residential, school, recreational, commercial fishing, hunting, gardening, playground, livestock grazing and crop production)
•A description of the land uses and size of local populations that have been exposed or may have exposure risk
•A description of the quality, use (that is, recreation, irrigation, livestock, drinking water, food production, etc.) and proximity of local groundwater and surface water resources; the presence of any USEPA designations as sole-source aquifer should be noted

- A description of the extent of contamination and the rate and direction of contaminant migration in the various transport pathways (air, soils, sediments, surface water and groundwater) on-site and off-site
- Description of fire and explosive hazards and potential adverse airborne releases

PRIORITIZATION OF HAZARDOUS WASTE SITES

CDC's S.P.A.C.E. for Health manual[14] explains how to assign and adjust the priorities of a hazardous waste site because of the potential impact on human health. Procedures for using all information gathered from the record, inspections and analyses to objectively assign site priorities in terms of public health are described in the manual. This priority can be used to make effective decisions about the funding of remedial actions, cleanup activities, further environmental testing and similar matters. Priorities may later need to be adjusted because of the results of further environmental testing, routine health monitoring, health studies or problems appearing during remedial actions.

The priority classification of a site is based on characteristics about the site, the contaminant of concern, the potential environmental pathways, the potential for human exposure/absorption and the health effects in the exposed population. The check list[14] at the end (Appendix 1) provides details in each of these categories.

CONCLUSION

A general outline of the items necessary for evaluating the public health significance of hazardous waste sites has been presented. The PHS/CDC has been the nation's focal point for conducting many of the public health evaluations of Superfund hazardous waste sites. Because of the enormity of the hazardous waste problem and the potential public health threat, identified hazardous waste sites need to be evaluated in a more timely manner. These potential health problems justify the State's playing larger roles in accomplishing these evaluations within budget constraints.

PHS/CDC intends to continue to be the nation's focal point for providing advice and support on the public health implications of hazardous waste sites, for national registries and inventories required by CERCLA, for conducting screening and health effect studies and for responding to public health emergencies due to hazardous and toxic substances. PHS/CDC also intends to continue to act as an advocate for the resources that States need to participate fully with CDC in this program. Only with the full cooperation of each State's public health and environmental/natural resources agencies can we make real progress in removing the public health threats posed by the multitude of hazardous waste sites and spills.

PHS/CDC depends upon and encourages constructive feedback from other Federal and State agencies to improve it evaluation procedures, protocols, information resources and recommendations provided to each region and State. CDC encourages your continued comments, particularly on its new S.P.A.C.E. for Health manual.

Appendix 1
Checklist for Use in Determining Priority of a Site

For each factor on the list, enter a check beneath the criterion level (0, 1, 2, 3, or unknown) that applies to the site.

		Unknown	0	1	2	3
1.	HAZARDOUS SITE					
1a.	Documentation of presence of hazardous site	no data/ no conclusion	uncorroborated allegations	historical records	observation of waste release	laboratory confirmation
1b.	Toxicity of 5 most hazardous substances at site (App. B - Tables 1, 2)	no data/ no conclusion	none	low	medium	high
1c.	Quantity of 5 most hazardous substances at site (App. B Table 3)	no data/ no conclusion	none	low	medium	high
1d.	Persistence of 5 most hazardous substances at site (App. B - Tables 2, 4)	no data/ no conclusion	none	low	medium	high
1e.	Concentration of 5 most hazardous substances (e.g., in water and soil on site)	no data/ no conclusion	≤ background levels	> background levels	greatly exceed background levels (or above standards)	above levels with significant harm potential
1f.	Site management and and containment (App. B - Tables 5, 6)	no data/ no conclusion	total control	adequate control	inadequate control	uncontrolled

	Unknown	0	1	2	3
1g. Potential for direct access to site	no data/ no conclusion	no direct access	occasional individual	small popula- tion with intermittent access	large popu- lation with repeated di- rect access

2. EXPOSURE POTENTIAL OF ENVIRONMENTAL PATHWAYS

	Unknown	0	1	2	3
2a. Ground water (App. B Table 7)	no data/ no conclusion	none	low	medium	high
2b. Surface water (App. B - Tables 8, 9)	no data/ no conclusion	none	low	medium	high
2c. Air	no data/ no conclusion	no suspected releases	rare reported releases; no apparent effects	intermittent releases; vague, infrequent complaints	repeated re- leases; levels ex- ceed stan- dards; fre- quent major complaints
2d. Deposition in (on) soil off site	no data/ no conclusion	absent or ≤ background levels	> background levels	greatly exceed background levels	above level with signi- ficant harm potential
2e. Presence in food chain	no data/ no conclusion	absent or background level	moderate in- crease over background but below FDA standard	at or near FDA standards	signifi- cantly above FDA standards

3. POTENTIAL FOR HUMAN EXPOSURE/ABSORPTION

	Unknown	0	1	2	3
3a. Presence of potentially exposed population (i.e., people living, working or otherwise occupied in area near site or or relevant pathway)	no data/ no conclusion	no people within 1 mile of site or relevant pathway	people within 1 mile but not in imme- diate vicinity (e.g., not within 1-2 blocks) of site or rele- vant pathway	small number of people (<100) in immediate vicinity of site or relevant pathway	large number of people (≥100) in immediate vicinity of site or relevant pathway
3b. Basis of evidence for human exposure/ absorption	no data/ no conclusion	unfounded allegations	historical records	highly sugges- tive data from environ- mental monitoring	results of biological sampling and/or presence of characteris- tic illness for relevant exposure
3c. Levels of substances found through biological sampling	no data/ no conclusion	substances not detected or < back- ground levels	small, pro- bably insigni- cant elevation over back- ground levels	significant elevation, clinical effects uncertain	exceed levels with potential for illness

	Unknown	0	1	2	3
4. HEALTH EFFECTS IN EXPOSED POPULATION					
4a. Allegations/reports of health effects	no data/ no conclusion	no allegations or reports	vague, non-specific, poorly characterized allegations	specific and well-documented reports, but effects of doubtful relevance for chemicals under consideration	solid reports of relevant effects for chemicals under consideration
4b. Results of clinical or epidemiologic studies conducted	no data/ no conclusion	good study with negative results	limited study with negative or insignificant results	scientifically limited study with positive or important findings	scientifically sound study with positive, significant findings
4c. Expectation of a currently observable (often acute or short-term) health effect	no data/ no conclusion	none expected	small expectation	moderate expectation	high expectation of current effect
4d. Expectation of a future (often chronic or long-term) health effect	no data/ no conclusion	none expected	small expectation	moderate expectation	high expectation of future effect
4e. Severity or public health impact of presumed health effects	no data/ no conclusion	negligible	minimal health effects, but widespread	potentially severe health effects, but uncommon	severe health effects, with widespread impact

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CHILDREN'S EXPOSURE TO SMELTER-ASSOCIATED LEAD, MONTANA AND IDAHO

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INTRODUCTION

Lead smelting has been a major industry in East Helena, Montana, and Shoshone County, Idaho, since the turn of the century. In both places, emissions from the smelters have contaminated nearby residential communities. In 1974, the average air lead level within 1 mile of the smelter in East Helena was four micrograms per cubic meter,[1] and the level within 1 mile of the smelter in Shoshone County was 17 micrograms per cubic meter.[2] For comparison, the present national ambient air quality standard is 1.5 micrograms per cubic meter.[3]

Children living in East Helena and in Shoshone County in 1974 and 1975 had elevated blood lead levels. Although samples were collected during the winter, when exposure to soil lead is minimal, 10% of the children in East Helena had whole-blood lead levels greater than 40 micrograms per deciliter (μg/dl), meeting the accepted definition at that time for elevated blood lead.[4] Summer sampling in Shoshone County in 1974 indicated 42% of the children had blood lead levels above 40 μg/dl.[5]

The findings in Idaho resulted in remedial actions aimed at reducing smelter emissions and limiting access to contaminated soils. Included were: (1) closing the smelter temporarily; (2) implementing smelter emission controls; (3) improving industrial hygiene practices at the smelter to reduce the amount of lead dust brought home by workers; (4) purchasing and destroying homes near the smelter after relocating residents to less-contaminated neighborhoods; (5) covering contaminated yards with imported soil and seeding these yards with grass; (6) providing water subsidies to promote the growth of the grass; (7) covering driveways and play areas with new sand and gravel; and (8) providing community education programs on how to reduce children's exposure to contaminated soil and household dust. In 1981, air lead levels in Shoshone County, Idaho, decreased markedly when the lead smelter closed.

In East Helena, Montana, remedial actions were taken in 1982 to reduce exposures to lead-contaminated dust, including (1) implementing a street-cleaning program; (2) planting trees around the smelter; and (3) building concrete bins for storing lead ore.

In 1983, to determine whether a public health problem persisted in East Helena and Shoshone County, questionnaire data and biologic and environmental samples for evaluating the children living in those smelter communities was collected. The study purposes were twofold. The first purpose was to identify children who had excessive blood lead levels with or without evidence of lead toxicity. Since 1974, new epidemiologic, clinical and experimental evidence has indicated that lead is toxic at levels previously thought to be non-toxic.[6-13] Currently, the Centers for Disease Control is revising its criteria for lead toxicity. The proposed levels are blood levels greater than or equal to 25 μg/dl and erythrocyte protoporphyrin (EP) greater than or equal to 35 μg/dl. The direct toxic effect of lead on heme biosynthesis is seen in increased levels of EP in whole blood. An elevated EP level thus can provide early and reliable evidence of biochemical toxicity due to lead.

The second purpose of the 1983 epidemiologic studies in Montana and Idaho was to determine the relative contributions to children's blood lead in these communities from lead-contaminated air, soil and dust and from host factor characteristics such as play habits and the occupations and hobbies of family members.

METHOD

Using geographic patterns of environmental lead contamination, three study areas in each community were defined. Area 1 included homes within a 1-mile radius from the smelter. Area 2 included homes from 1 to slightly more than 2 miles away. Area 3, the comparison area, consisted of a nearby neighborhood selected for having age, race and socio-economic characteristics similar to those of Areas 1 and 2. In both Montana and Idaho, Area 3 was about 5 miles west of the smelter, a direction which is usually upwind.

A door-to-door census was used in each study area to identify which families had lived in the community for 3 months or more and, in Montana, had children 1-5 years old and in Idaho 1-9 years old. Older children were included in Idaho so that the results could be compared with results of previous studies. Survey teams visited the eligible households with questionnaires, collected environmental samples, and, in Montana, drew blood samples from the children. In Idaho, blood samples were collected at a local clinic.

The questionnaire design used in Montana and Idaho permitted a parent to select the best of several precoded responses to describe the habits of individual children and the characteristics of the household. Questions on each child's habits addressed (1) oral activity (e.g., whether the child ate snow, used a pacifier, sucked a thumb, chewed fingernails, carried a favorite blanket or toy around during the day and put this in his or her mouth, placed his or her mouth on furniture, placed paint chips or other objects in his or her mouth, or swallowed foreign objects); (2) play environment (e.g., did the child play with other children or adults, stay at home to play, play indoors or outside, take food outdoors during playtime, spend time on the floor, play on grass, dirt or concrete surfaces outside?); (3) routine hygiene practices (e.g., were the child's hands usually washed before eating, before going to sleep, and after playing with dirt or sand?); and (4) dietary supplementation with minerals and vitamins. Questions on the characteristics of the household addressed socio-economic status, length of time in

residence, lead-related occupations and hobbies of family members, use of fruits and vegatables grown in the neighborhood, food storing and serving practices that might increase the lead content in the family diet; year of house construction; and presence of a smoker in the household.

To identify the sources of lead in the children's usual surroundings, the survey teams collected composite samples of soil from front and back yards of each house. Samples of household dust were also collected, using both floor wipes and samples from vacuum cleaner bags. When available, samples of garden vegetables were collected for heavy metal analysis. To determine the amount of lead present in painted surfaces inside and outside each home, hand-held X-ray fluorescence (XRF) analyzers were used. Data on ambient air lead were collected throughout the study at air monitoring stations in each of the three study areas.

Blood samples were analyzed by ESA Laboratories, Massachusetts, for blood lead, EP and hemoglobin. EP concentration was determined by the extraction method. Environmental samples (soil, dust and vegetables) were analyzed by the Silver Valley Laboratory, Idaho, and the Montana Department of Health and Environmental Sciences.

RESULTS AND DISCUSSION

Blood-Lead and EP

The numbers of eligible children, i.e., those who met the age and residence criteria, were 437 in Montana and 400 in Idaho. Tables 1 and 2 give the number of eligible children and the number of children tested in each study area in Montana and Idaho. Participation rates in Montana were highest in Area 1 (95%), the Area closest to the smelter, and lowest in Area 3 (77%), the comparison area. In Idaho, Areas 1 and 3 both had participation rates of 94%.

Tables 3 and 4 give the results of children's blood lead and EP levels in Montana and Idaho. The log-transformed mean blood lead data in both areas were consistently and statistically significantly higher for children living near the smelter (p < 0.001). In addition, children in Idaho Area 1 who were born after the smelter closed in 1981 had a mean blood lead level of 22 μg/dl.

Six percent of the children who lives in Area 1 in Montana had blood lead values that showed excessive lead absorption (i.e., 25 μg/dl). No child who lived outside Area 1 in Montana had a blood lead value of 25 μg/dl or greater. In comparison, relatively high

Table 1
Numbers of Eligible and Tested Children, Montana

Area	Dist. from Smelter (miles)	No. of Eligible Children*	No. of Children Tested
1	< 1	104	98 (95%)
2	1-2.25	254	238 (94%)
3	> 5	79	60 (76%)
Total		437	396 (91%)

*1-5 years of age

Table 2
Numbers of Eligible and Tested Children, Idaho

Area	Distance from Smelter (miles)	No. of Eligible Children*	No. of Children Tested
1	< 1	46	43 (94%)
2	1-2.25	223	199 (90%)
3	> 5	131	122 (94%)
Total		400	364 (91%)

*1-9 years of age

Table 3
Blood Lead and Erythrocyte Protoporphyrin (EP) Levels, Montana (μg/dl)

	Blood Lead			Erythrocyte Protoporphyrin			
Area	Mean	% 25	N*	Mean	% 35	N**	No. of Children with Lead Toxicity†
1	13	6	6	22	8	8	1
2	9	0	0	21	4	9	0
3	6	0	0	20	3	2	0

*Number of children with blood lead μg/dl
**Number of children with EP μg/dl
†Blood lead 25 μg/dl and EP 35 μg/dl

Table 4
Blood Lead and Erythrocyte Protoporphyrin (EP) Levels, Idaho (μg/dl)

	Blood Lead			Erythrocyte Protoporphyrin			
Area	Mean	% 25	N*	Mean	% 35	N**	No. of Children with Lead Toxicity†
1	21	15	15	35	42	17	11
2	17	11	29	26	17	34	17
3	12	5	6	21	10	12	2

*Number of children with blood lead 25 μg/dl
**Number of children with EP 35 μg/dl
†Blood lead 25 μg/dl and EP 35 μg/dl

percentages of children in Idaho Area 1 (35%) and Area 2 (15%) had blood lead values greater than 25 μg/dl.

The log-transformed EP levels in Idaho were consistently and significantly higher for children living near the smelter (p 0.05). No significant differences were found in mean EP levels among the three study areas in Montana.

Table 5
Mean Air Lead Levels (μg/m³), Montana and Idaho August-October 1983

Area	Montana	Idaho
1	3.70	0.28
2	0.98	0.12
3	0.23	0.10

Table 6
Mean Lead Levels (ppm*) in Soil and House Dust, Idaho

Area	Soil	House Dust
1	6,059	4,136
2	3,432	4,875
3	677	1,361

*parts per million

Children with iron deficiency anemia may have elevated EP values in the absence of lead exposure. To determine whether the similarity of EP levels among the three study areas in Montana could be due to a confounding effect of iron deficiency anemia, blood hemoglobin data were analyzed. Out of 396 children who had blood samples analyzed for EP, only three had low (i.e., less than 11 grams per deciliter) hemoglobin concentrations.

One child in Montana and 30 children in Idaho had lead toxicity, as defined by having both a blood lead level of at least 25 μg/dl and an EP value of at least 35 μg/dl. No child had high blood lead levels (i.e., ≥ 55 μg/dl) that required chelation therapy.

Table 7
Mean Lead Levels (ppm*) in Garden Vegetables, Idaho

Area	Vegetables	Mean Lead Level	No. of Samples
1	Carrots	18	3
	Beets	0	0
	Lettuce	48	1
2	Carrots	61	23
	Beets	47	14
	Lettuce	65	25
3	Carrots	25	32
	Beets	16	9
	Lettuce	32	20
Total			127

*parts per million

Table 8
X-Ray Fluorescence (XRF) Analysis of Lead in Household Paint, Idaho

Lead Category	XRF Reading (mg/cm²)	Number of Surfaces Tested
Negative	< 0.7	1,133 (78%)
Low	0.7-2.9	186 (13%)
Moderate	3.0-5.9	75 (5%)
High	≥ 6.0	66 (4%)
		1,460

Air Samples

Table 5 gives the mean air lead levels during the study period in Montana and Idaho. The mean air lead levels in Areas I and II in Montana exceeded those in Idaho by a factor of 10; this difference reflects the absence of active smelting in Idaho.

Soil and Dust

Laboratory analyses of environmental samples (soil, dust, and vegetables) from Montana have yet to be completed. Table 6 gives the mean lead levels found in soil and house dust in Idaho. Within each study area in Idaho, soil lead levels collected from adjacent yards varied greatly. No concentric pattern or other consistent distribution of lead in the soil of the three study areas were noted. The absence of such a pattern may be due to the remedial actions taken in 1975 when selected residential yards were covered with imported soil and selected playgrounds were covered with new sand and gravel. Those actions may also account for the fact that in 1983 the highest values in samples of yard soil (41,200 ppm) and of garden soil (5,160 ppm) were found in Area II rather than in Area I.

Samples of house dust taken from vacuum cleaner bags showed higher lead levels in Idaho Area I (4,136 ppm) and Area II (4,875 ppm) than in Area III (1,361 ppm) by about threefold.

Garden Vegetables

Table 7 gives the mean lead levels found in garden vegetables in Idaho. Most of the samples were collected in Areas II and III. Although lead levels in carrots, beets, and lettuce were about half those found in 1974 and 1975, the average levels in Area II remained two to three times higher than the levels in Area III.

Lead in Paint

Table 8 gives the X-ray fluorescence (XRF) data on lead concentrations in household paint in Idaho. These data show a low prevalence of leaded paint in the homes of study participants. No correlation was found between children's high blood lead values and residence in homes with high lead paint values.

Questionnaire

The questionnaire data are now being analyzed. A major hypothesis to be tested is the relationship between children's oral activities and blood lead levels.

SUMMARY

The 1983 epidemiologic study of children's exposure to lead in East Helena, Montana, showed that children who lived near the smelter had higher blood lead levels than those who lived farther away. After completing the laboratory analyses of environmental samples, the relative contributions to the blood lead levels from the lead levels in air, dust, and soil and from the children's play habits and family characteristics will be determined.

The 1983 epidemiologic study of children's exposure to lead in Shoshone County showed that children who lived in areas with high levels of lead in the soil were more likely to have elevated blood lead levels than children living in areas with cleaner soils. Specifically, within 1 mile of the smelter, where the mean soil lead level was 6,059 parts per million, the blood lead level of 35% of the children was 25 μg/dl or higher. These blood lead levels were considered to be excessively high, and they may result in adverse health effects.

Since a child who eats a half-cup serving of vegetables containing 15 ppm of lead would be ingesting an amount of lead exceeding the recommended maximum daily intake, it is recommended that children not eat leafy or root vegetables grown in any of the three study areas in Shoshone County, Idaho.

Of special interest in Idaho was the finding that 1- and 2-year-old children within 1 mile of the smelter had a mean blood lead level of 22 μg/dl. Since these 11 children were born after the smelter closed in 1981, they have not been exposed to high air lead levels. Unless they had been exposed to some unusual source of lead, these children would be expected to have a mean blood lead level of about 6 μg/dl. Since air lead levels in Idaho in 1983 were low and since very little leaded paint was found in the homes studied, the main source of lead exposure probably has been the contamination in the dust and soil. This hypothesis will be tested in multivariate regression analyses.

The environmental sources of lead in 1983 in Shoshone County, Idaho, were more diffuse than those in 1974, and the children's blood lead levels were lower. It is suspected that these characteristics of the data may substantially limit the predictive power of the final multivariate model. Thus, the final model for explaining children's blood lead levels in Shoshone County may leave most of the variance in these levels unexplained.

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THE USE OF SERUM REFERENCE MATERIALS AND STATISTICAL METHODS IN THE CLASSIFICATION OF HUMAN EXPOSURE TO PCBS AT WASTE SITES

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INTRODUCTION

The improper dumping of waste from various industrial processes into landfills, waterways and rock quarries has created toxic waste sites throughout the United States. In 1980, Congress passed CERCLA to provide money for finding, cleaning up and controlling these toxic waste sites. State agencies and the USEPA have worked together to find these sites and rank them on the basis of the type and quantity of waste on the site and the potential risk posed to public health.

The Centers for Disease Control (CDC) has been involved in assessing the health of persons living near specific waste sites. The model[1] shown in Figure 1 illustrates the potential ways that toxic chemicals found in waste sites can get into environmental pathways—which are simply soil, air, water and the food chain. Human exposure can result from ingestion, inhalation and/or dermal absorption.

Human exposure has to be proven. It cannot be assumed. It must be shown that humans bodies contain a particular chemical or its metabolite that is found at a specific dump site. This is often difficult for three reasons:

- Many of the chemicals found at the dump site have short half-lives in mammals.
- People may have had only intermittent exposure to the dump site, resulting in exposure levels below the detection limits of available analytical methods.
- Most people have low "normal" background levels of certain persistent chemicals from exposure through the food chain.

Certain chemicals found in waste sites have these characteristics: (1) they have long half-lives; (2) they are stored in human bodies; (3) they can be identified analytically; and (4) continuing low-level exposure to them could result in adverse long-term health effects. Polychlorinated biphenyls (PCBs) have these characteristics. In addition, their presence at waste sites is so widespread that the Mitre Corporation used PCBs as part of the basic criteria for ranking hazardous waste sites.[1]

The amount of PCBs in a person can be estimated by analyzing serum and fatty tissue. Since the average amount of PCBs in the general American population has been estimated, comparisons can be made between the body burdens of persons exposed to specific waste sites and the general population.

CDC personnel experienced in evaluating health problems connected with waste sites have designed a pilot study for use in cooperation with local health departments and the USEPA, to determine the amount (body burden) of PCBs in persons living close to the 20 highest-ranking waste sites. CDC personnel also have developed—and described in a paper not yet published—a multistage plan that would be cost effective because only those individuals with the most significant PCB-exposure would receive further study. The suggested four stages of this study are:

- *Site ranking.* Review environmental and population data on all toxic waste sites with high PCB levels in pathways to which people could be exposed, and select for the pilot studies those sites with the greatest potential for human exposure.
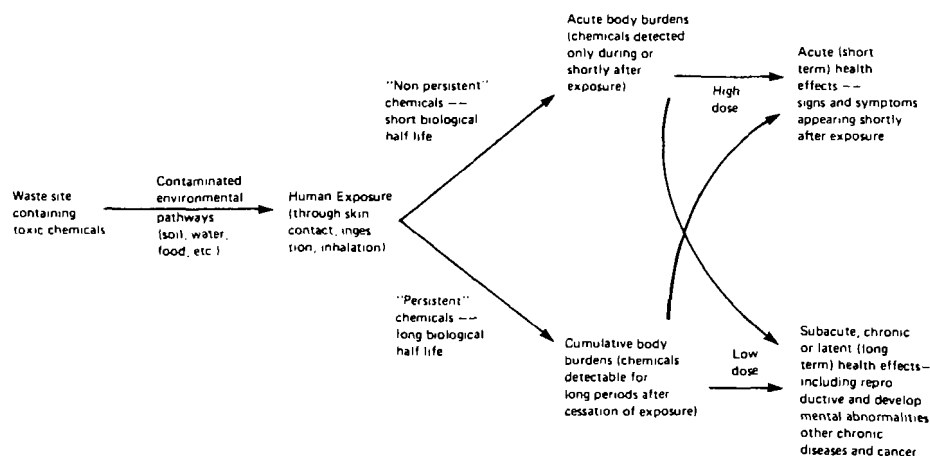
Figure 1
Model of Potential Human Health Effects Related to Chemical Exposures from Toxic Waste Sites from E.R. Welty *et al.*, Unpublished Data, CDC.

• *Pilot exposure studies.* By using questionnaires and environmental data, select the most heavily exposed persons chosen in Stage 1 and measure their serum PCB levels. In instances of exposure of lactating mothers, analyze breast milk for PCBs.

• *Community surveys.* At those sites where Stage 2 studies showed elevated serum PCB levels, conduct cross-sectional, community-wide studies to determine health effects.

• *Cohort studies.* On the basis of data from Stages 2 and 3, register persons with markedly elevated PCB levels for long-term follow-up to evaluate any chronic health effects.

These studies are intended to: (1) evaluate the health risk of persons living near dump sites; (2) indicate the proper health measures to be taken; and (3) provide a model for assessing other hazardous substances. CDC also recognizes a need for a qualitative way to find the source of the PCB exposure. One method is to use specifically prepared serum reference materials. This study could be done simultaneously with the other investigations.

PCBs are usually found in a metabolized or degraded state, and the nature of the original PCB exposure is difficult to determine. This is why basic reference material is so important. In the work described here, specific PCBs are given to test animals, and the resulting blood samples are used as reference material. Suspected human PCB exposure can be checked by multivariate analysis to compare the relationship between the human sera samples and the reference materials. Analysts have attempted to quantitate PCBs using Aroclor® standards that produce patterns similar to or compatible with the matrix pattern.

For congener-specific identification of PCBs, some analysts, as well as members of the CDC analytical group, have used capillary gas chromatography (CGC) with electron capture detection (ECD) or CGC with gas chromatography mass spectrometry (GC-MS). The main problem with this approach is the lack of standards for comparison. The PCB data in this report were obtained by using packed-column gas chromatography (PCGC), ECD and Webb-McCall[3] mean-weight percent values.

PREPARATION OF REFERENCE MATERIAL

Before the serum reference material was prepared, the following decisions were made: (1) which Aroclor® (AR) series were to be dosed; (2) which animal species was to be dosed; and (3) what dosage level was to be used. The Aroclors® were chosen on the basis of domestic sales since 1971 and how they were used—that is, in a closed system, a normally closed system or an open-ended application.[4] On the basis of this information, four Aroclors® were fed singly. They were AR 1016, AR 1242, AR 1254 and AR 1260. Those fed in combination were AR 1254/1016, AR 1254/1260, AR 1254/1242 and AR 1242/1260.

Adult female goats were selected for the tests because of minimum cost. The dosage level (100 mg/kg each Aroclor®) was used because an earlier study had shown that this dosage provided an approximate 100 μg/l serum level in 30 days. Each goat was first tested for Aroclors® and chlorinated hydrocarbons (as DDT, DDE and others). The serum showed no significant amounts of any of these chemicals. In this way, each goat served as its own control. The goats then were force-fed gelatin capsules containing the neat Aroclors® . Each goat otherwise was fed a normal diet and kept in an individual stall.

At the time of dosing, it was discovered that all the goats were pregnant except the one fed AR 1254. About 30 days after the kids were born, blood samples were taken from the mothers. The procedures used in the preparation of these samples are outlined in Table 1.

Table 1
Preparation of Reference Serum Materials

1. Female goats—average weight—41.9 kg
2. Dosed orally (capsules) with a single Aroclor (100 mg/kg) or a combination of two Aroclors each at 100 mg/kg
3. 30 days later each goat was exsanguinated
   A. Serum obtained
   B. Sterile filtered (millipore)
   C. Dispensed (2-3ml) into screw cap vials
   D. Stored at – 40 °C

GAS CHROMATOGRAPHIC (GC) PATTERNS

The GC-ECD profiles of the Aroclor² standards used in the feedings are shown in Figure 2. The GC-ECD profiles obtained from sera after dosage (≥30 days) are shown in Figure 3 (single) and Figure 4 (combination). The analytical method used to obtain the GC traces has been reported,[3] except that the GC column temperature was increased from 190 °C to 205 °C.

For single Aroclors® (in vivo), peaks are identified with relative retention times (RRT) to DDE (DDE x 100). In the combination Aroclors® (in vivo), peaks are identified as possibly being derived from a particular Aroclor² or Aroclors² on the basis of the GC traces obtained when only one Aroclor² was fed.

The concentration of certain Aroclor[f] peaks differed notably between the dose with one Aroclor² and those with combinations (Figs. 3 and 4). These differences appear primarily for the early eluters in AR 1016 and AR 1242. It is not known whether these apparent differences in concentration are due to the pharmacodynamics of feeding two dissimilar Aroclors² in combination or to the nature of the ECD response to these types of compounds.[6] This problem will be investigated later.

Figure 2
Gas Chromatographic Profile (Electron Capture) of Aroclors™ Fed

Figure 3
Gas Chromatographic Profile of Single Aroclors® ≥ 30 Days
After Dosage

Figure 4
Gas Chromatographic Profile of Combined Aroclors® ≥ 30 Days
After Dosage

SELECTED INCIDENCES OF HUMAN EXPOSURE

Human sera from three cases of alleged PCB exposure provided samples for comparison with the reference materials from the goats. The cases of alleged human exposure are outlined in Table 2.

The human serum tests can be compared visually with the goat reference serum tests in Figures 5-7. Note the similarities between the RRT of the human cases and the reference sera. Each case (except C) is shown with the in vivo Aroclor® profile that "best" relates to the Aroclor® used to quantitate the case. Case C, although quantitated as AR 1260, contained early eluting peaks (pre-DDE) indicating possible exposure to AR 1016 or AR 1242.

Table 2
Selected Cases of Alleged Exposure to PCBs

Case	Background	Quantitated as Aroclor (ppb)
A	A farmer who used Coumar® as a sealant for his silo.	1254 (172)
B	A composite sample from a Kansas family that had consumed contaminated beef.[7]	1260 (307)
C	A composite sample from residents of New Bedford, Massachusetts.[8]	1260 (31)

DATA ANALYSIS OF GOAT AND HUMAN SERA

Serum from each dosed goat was analyzed four times. Serum from each human case was analyzed once. Gas chromatograms were characterized by relative retention times with respect to (DDE x 100), resulting in the identification of 59 peaks.

The responses for all peaks were computed as area-%/mg of serum injected. Peaks with responses of less than 0.25% (an arbitrary cutoff) were deleted, and peaks with relative retention times within ± 5% were combined. This resulted in 28 distinct peaks present in at least one sample; that is, in a sample from one of the three human cases or in a sample from one of the eight goats used in the 32 analyses.

Although other statistical techniques—for example, SIMCA[9]—are available for handling data of this kind, only two will be used. The first, principal components[10, 11], will be used to analyze the area-percent data. This is a technique for finding a new coordinate system so that most of the variability in the original 28-dimensional space is (in this case) in the 2-dimensional plane defined by the first two principal components.

Figure 5
Gas Chromatographic Profile of Case A and In Vivo AR 1254 ≥ 30
Days After Dosage

Figure 6
Gas Chromatographic Profile of Case B and In Vivo AR 1260 ≥ 30
Days After Dosage

Figure 7
Gas Chromatographic Profile of Case C and In Vivo AR 1016 and
AR 1242 ≥ 30 Days After Dosage

The second technique uses only the presence or absence of a peak at each of the 28 relative retention times as the basis of analysis. For each pair of gas chromatograms, a Jaccard coefficient[12] was computed to measure the similarity between the gas chromatograms. This coefficient is the number of relative retention times for which both gas chromatograms showed a peak, divided by the number of relative retention times for which at least one of the two gas chromatograms has a peak. Thus, this measure of similarity is between zero (no peaks in common) and 1 (identical peaks).

The similarity between the different analyses done on serum from a single goat, between the analyses of sera from two different goats or between serum from a goat and serum from a human case was computed as the average of the similarities between the corresponding pairs of gas chromatograms. In particular, the similarity between the four gas chromatograms done on serum from a single goat was computed as the average of six coefficients obtained from all possible pairs of gas chromatograms. Thus, this quantity describes the stability of the measurement process on different aliquots from a single animal.

Similarly, the agreement between the gas chromatograms done on sera from two different goats was obtained by averaging 16 coefficients; and the agreement between the gas chromatograms done on serum from a goat and serum from a human case was obtained by averaging four coefficients. This measure of agreement is analogous to a correlation coefficient.

The results of the principal components analysis are shown in Figure 8. This scatter plot shows the coordinates for each gas chromatogram with respect to the two coordinate axes (in 28-dimensional space) defined by the first two principal components. The gas chromatograms corresponding to the goats fed single Aroclors® are separated and distinguishable on the scatter plot. Gas chromatograms of sera from goats fed combination Aroclors® tend to be more similar to the pattern corresponding to the Aroclor® with the higher chlorine content. This is not surprising when the stability of the higher chlorinated Aroclor® is considered.

The human sera evaluated by this technique are not as clearly delineated. Serum from Case A, a suspected 1254 exposure, does appear similar to 1254.[13] Composite sera from Case B, a suspected 1260 exposure, do not appear as similar to 1260, however, as the visual comparison of the gas chromatographic analysis (see Figure 6) would indicate. Composite sera from Case C, although quantitated as AR 1260, produced early eluting peaks (pre-DDE) which are considered indicative of exposure to AR 1016 and/or AR 1242. The principal components analysis indicates that Case C sera are more similar to AR 1016 and AR 1242 than to the other Aroclors®.
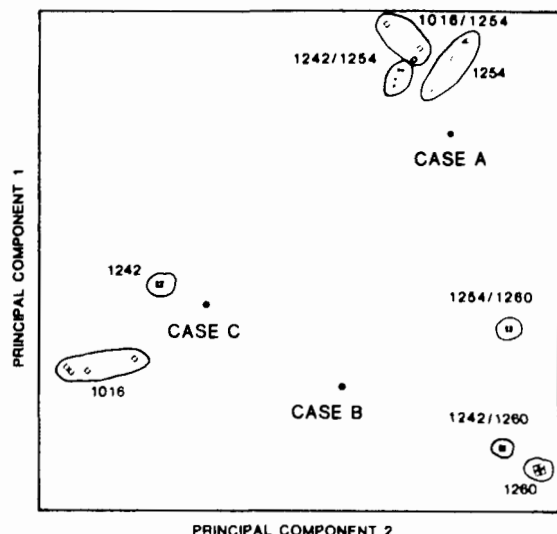
Figure 8
Principal Components Analysis for Goats and Selected Cases

Table 3
Similarity Measures* of Gas Chromatograms for Dosed Goats and Cases

Dosed Goats	1260	1242/1260	1254/1260	1254	1242/1254	1016/1254	1242	1016
1260	1 00	68	67	.41	33	32	.16	08
1242/1260	68	.96	68	.50	60	52	45	28
1254/1260	67	68	96	72	60	59	35	15
1254	41	50	72	1 00	80	81	48	.22
1242/1254	33	60	60	80	96	87	66	34
1016/1254	32	52	59	81	87	.92	60	28
1242	16	45	35	48	66	60	90	30
1016	08	28	15	.22	34	28	30	61
Case A	37	45	51	53	51	51	34	18
Case B	62	46	40	31	29	29	12	12
Case C	42	70	61	59	74	66	49	31

*Similarity measures are averages of Jaccard coefficients, as defined in the text.

The Jaccard measures of similarity are given in Table 3. They show the same general pattern as the principal components analysis, with some interesting differences. The agreement for the different gas chromatograms from a single goat is excellent (at least 90%) except for the goat fed 1016; one of the four gas chromatograms from the latter showed many abnormal peaks. Deletion of that aberrant gas chromatogram raised the average similarity among the gas chromatograms of the goat fed 1016 to 80% but had little effect on the other similarity estimates for human cases or for the other goats. Gas chromatograms from pairs of goats fed the same Aroclor® (one alone, one in combination with another Aroclor®) generally show high similarity (at least 60%), except for the 1016 versus 1242/1260 pair (similarity 45%). This anomaly was also detected by comparing the gas chromatograms visually (Figs. 3 and 4).

In general, the similarity patterns found among the gas chromatograms from the goats are similar to the patterns suggested by the principal components analysis. The principal components analysis suggests, however, that AR 1016 and AR 1242 are similar, whereas the similarity measures show an agreement of only 30% between the gas chromatograms for these Aroclors®.

The similarity measures suggest that the gas chromatograms from Case A are most similar to the pattern found in 1254, as did the principal components analysis. This simple measure of similarity identifies Case B as a suspected exposure to 1260, in agreement with the alleged exposure, but the principal components analysis does not make such a clear identification. Finally, the similarity analysis suggests that the gas chromatograms from Case C most closely resemble the patterns from AR 1242/AR 1254, AR 1242/ AR 1260 and AR 1016/AR 1254 in contrast to the principal components analysis, which suggests that the gas chromatograms from this case are most like AR 1242 alone. The composite sample from Case C comes from residents of New Bedford, Massachusetts, who may have consumed contaminated shellfish, finfish and lobster. Industries in this area were known to use more AR 1242 than AR 1016 or AR 1254.[?]

These discrepancies between principal component analysis, Jaccard measures of similarity and visual examination of gas chromatograms demonstrate the difficulty associated with ascertaining the nature of Aroclor® exposure. The techniques used in this report are preliminary and experimental; it is hoped, however, that in vivo reference material will prove useful in delineating Aroclor® exposure in people who live in proximity to waste sites.

DISCLAIMER

Use of trade names is for identification only and does not constitute endorsement by the Public Health Service or by the U.S. Department of Health and Human Services.

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EMERGENCY PLANNING FOR ABANDONED WASTE SITES

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INTRODUCTION

"Emergency" is a sudden, usually unexpected, change which requires immediate corrective action. That definition is used in this paper and includes terms such as "accident", "incident", "event", and "happence", as synonyms for "emergency". Therefore, in any hazardous material situation, any sudden change in circumstances which prompts special corrective actions will be termed an "emergency," and those corrective actions will be termed "emergency procedures". However, under this definition, not all sudden changes are emergencies.

The consequences of being unprepared to take proper corrective actions for emergencies at abandoned hazardous sites can be severe. Generally, most emergencies which lack advance preparations are characterized by the panic and confusion which prevails over all proper response activities. Personnel and visitors to the area begin to react on impulse; some run away from the emergency, while others run toward it. The response becomes haphazard, with several separate responding teams (if any) reacting without coordination and lacking a clear understanding of the scope of the situation.

To establish a coordinated, effective response to any emergency situation, the OSC must determine the following within the first few moments of the emergency:
- The type of emergency
- How to gather needed information
- How to distinguish rumor from fact
- The time requirements for the information gathering
- Time available before corrective actions are required
- Available response options
- Potential for wrong actions which could compound the situation
- How to determine the success or failure of the response action

Time is the crucial element of any emergency response. Time is required for identifying the emergency, choosing the control strategy and executing the plans properly; yet the need remains for more time than is available. One way to increase the amount of time available for response to an emergency is to use some time before any emergency to plan and rehearse a proper response.

TYPES OF EMERGENCIES

To formulate the best plans and procedures for on-site emergencies, one should be aware of the types of emergencies to prepare for. There are two major classes of possible emergencies; (1) one involving the workers and (2) one involving the wastes. The two types of situations will involve completely different response actions, even if the emergency includes both workers and wastes. The equipment, procedures and training for worker-related incidents, which would require rescue and first aid, are totally different than those required for waste-related actions, which would suggest containerization procedures and fire-fighting. Therefore, it would be advantageous to have two emergency action teams trained and prepared for the differing aspects and types of emergencies. Key considerations for each of these teams are:
- Something occurring to the worker
  - accident
  - physical injuries
  - equipment failure
  - medical problems
  - chemical exposure
- Something occurring to the wastes
  - leaks
  - collapse of containers
  - fire/explosions
  - incompatible reactions
  - release of toxic vapors

While many emergencies might be combinations of any of the incidents mentioned, each aspect cited requires different procedures, equipment and training. Tables 1 and 2 contain examples of the actions which are typically either "rescue" or "response".

WORKER-RELATED EMERGENCIES

Trips and Falls

Accidents, such as slips, trips or falls, are among the most common incidents and when no physical injuries result, are commonly overlooked. In the situation where a worker trips and simply gets up and proceeds as normal, few people would give such a minor incident any notice. However, at hazardous waste sites, it is important to limit unnecessary contact with waste materials; falling to the ground would place wastes directly on protective clothing which does not have the thickness of the footwear. Consequently, permeation breakthrough occurs sooner. A person who falls while on-site should at least proceed through a minimal decontamination procedure before continuing with his tasks or assignments. On-site safety stations can include wash basins for such incidents.

Workers who trip while wearing "level A" protective equipment are not likely to be able to get up immediately even if they are uninjured, due to the bulk of their equipment. Communications are necessary in such cases to allow others to know that there is no injury so emergency rescue procedures are not initiated unduly.

Table 1
Examples of Rescue Activities

- Approach hazard scene carefully
- Extricate trapped victim
- Secure and remove unconscious victim
- Communicate with conscious victim
- Remove conscious victim from hazard area
- Emergency decontamination
- Emergency first aid
- Transport victim to hospital
- Reentry to obtain samples of wastes and/or air
- Monitor rescue party for possible exposure

Table 2
Examples of Response Activities

- ■ Evacuate immediate area
- ■ Firefighting using
  - water
  - foam
  - dry sand or dirt
  - carbon dioxide
  - dry chemicals
- ■ Containment using
  - dikes
  - booms
  - diversion ditches
  - plug/patch methods
  - repack or overpack
- ■ Shut off feed
- ■ Isolation of emergency scene from other site areas
- ■ Monitor response crew for possible exposures

Many accidents do involve physical injury, however, and everyone should know what to do in these cases. The injured worker must have some manner of communicating his injury to others and his rescuers should know the proper first aid and rescue procedures to follow in a hazardous situation so they do not unnecessarily expose the victim to the chemical wastes or aggravate the injury.

Physical injuries can occur as a result of an accident of the "slip, trip or fall" variety or from some external physical blow resulting from falling objects, explosions or other causes. The injury range includes broken bones, torn skin or damaged muscles. The care required for an emergency involving physical injury is well explained in many First Aid manuals; however, extra measures must be taken when the victim is in a hazardous situation or area.

Equipment Failure

Another purely physical problem which can trigger an emergency involving site workers is equipment failure. Abandoned chemical waste sites have several widely varied types of hazards against which the workers are protected by the wearing of certain types of protective clothing and respiratory equipment. The most obvious type of possible equipment failure would involve the respiratory devices, especially the SCBA. Any failure of a SCBA is going to place that worker in immediate danger.

If a worker is wearing an SCBA, then it is presumed that the external atmosphere is not fit to breathe and the safety areas are likely too far to reach before panic sets in. Although respiratory equipment is generally checked before each use, an emergency involving air source failure is important enough to plan and prepare for, even when considering the small chance of occurrence.

Other more common, but less panic oriented situations of equipment failure include: failure (by tear, penetration or permeation) of the protective clothing, fogging of face plates to zero visibility and failure of air-purifying respiratory devices. In some cases, the failure of equipment might not even be noticeable by the worker using the equipment.

Medical Emergencies

Medical problems are distinct possibilities for sudden emergencies. Heat stress in the field, coupled with the heat capturing abilities of the protective clothing, resistance to breathing of any respiratory protective devices and the work load which is increased by the bulk of protective devices, can bring about heat stress and heat stroke. The increased heat and work loads can aggravate existing medical conditions. Even though thorough medical screening is performed on the workers beforehand, the abnormally stressful working conditions can aggravate minor conditions into major problems.

Typically, one could expect to discover stroke, heart failure, asthma, bronchitis, distortion of the senses (especially the sense of balance) or attacks of claustrophobia. A background physical which includes an exercise to place stress on the cardiovascular system is preferable.

Chemical Exposure

The last class of incidents which can affect site workers is exposure to chemical agents. The wide variety of chemical wastes, where each waste is composed of numerous chemicals, means that the toxic agent will not be identified in most cases of chemical exposure. Most first aid responses to poisoning, as well as the medical responses in a hospital, depend greatly on knowing the identity of the toxic agent and the route of exposure.

At abandoned hazardous waste sites, one would be lucky if he could distinguish a chemical exposure from infection, such as the flu, let alone be able to positively identify the nature of the chemical to which the worker was exposed. Even in cases of direct contact with wastes, such as skin contact from splashing, the waste would be composed of so many different chemicals that the effects and proper treatment would be difficult to determine. Therefore, safety crews at remedial action sites should know beforehand what procedures to follow in cases of known and suspected exposures.

WASTE-RELATED EMERGENCIES

Leaks

Leaks and releases are the most common occurrence at older abandoned sites. Most such situations are looked at as commonplace and seldom as emergencies. Determining which leaks would require an emergency response, and which ones would be treated as normal remedial responses, is entirely up to the discretion of the OSC. Some of the factors to be considered include:
- Amount of material leaking (measured by volume/time and by volume-yet-to-be-released)
- Hazardous nature of the released material
- Impact on environment and neighboring population
- Time requirements for effects of pollutant to be felt

Plug and patch kits, overpacks and other containment measures should be available to control chemical releases, and staff should be trained to use them.

One of the ways in which leakage occurs is the collapse of the containers; the drums or tanks deteriorate over time and sometimes the actions of sampling are enough to cause the final collapse of the containers. Therefore, all investigation visits should include the preparation of sealing leaks and control of collapsing tanks or stacks of drums. The preparations should include not only the containerization of spilt chemicals but also any exposures and injuries that might occur to workers within the immediate area.

Fire

Of all the hazardous properties of chemical wastes, the flammable nature of contained materials is recognized as one of the major risks in site work. Although a fire can be easily ignited, extinguishing it may prove very difficult. Chemical fires are very difficult to fight because different chemicals can require different fire-

fighting techniques. While water will spread certain light solvents, other chemicals require foam or dirt to smother the fire. Some materials cannot be smothered at all since they provide their own oxidizing source and are so classified. Some materials are water reactive, while some are air reactive. Thus, the wide variety of requirements for chemical firefighting turns waste site fires into nightmares for everyone involved.

Explosion

Another aspect of waste site fires is explosion. Explosions can occur due to the unstable nature of the chemical compounds (detonation) or due to the rapid combustion of a containerized material (deflagration).

One type of emergency which can be triggered during remedial actions is a reaction due to the mixing of incompatible chemicals. Despite careful analysis of the various chemicals, the blending of incompatible substances can, and does, occur during site cleanup. The results of such reactions can range from toxic gas generation to fire and explosion. Once blended together, there is little that the OSC can do to halt the chemical reaction until it is complete. The response to severe incompatible reactions would be to treat the effects of any fire or explosion and to containerize as much of the released chemical as possible.

Vapor Release

During any leak, chemical release, incompatible reaction or fire, it is likely that toxic vapors may be released. Because most of those vapors are invisible, one should have a monitoring system in place to detect a variety of vapors and gases. For example, when bulk wastes are solidified with lime, clouds of water vapor are usually released due to the heat of reaction. It is important to remember that many organic solvents have lower vapor pressures and boiling points than water, and so entrained solvents would be released with the water vapor.

CONCLUSIONS

The prevention of any site emergency is only one half of emergency planning. As discussed, the other half involves recognizing the possible hazards and formulating the proper reactions far enough in advance to ensure smooth and effective emergency responses.

The response to a waste-related emergency involves different equipment (e.g., containment kits, firefighting equipment) than is used in worker rescue operations (e.g., first aid and decontamination equipment). Any emergency plan should require different response actions and equipment.

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GUIDING PRINCIPLES IN THE DESIGN OF MEDICAL SURVEILLANCE PROGRAMS FOR HAZARDOUS WASTE WORKERS

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INTRODUCTION

Evaluation and remediation of uncontrolled hazardous waste sites is a rapidly growing industry. Employment, already in the thousands, is sure to grow. Improved techniques for dealing with uncontrolled hazardous waste sites emerge almost daily, indicating a steady improvement in the "product" of this industry.

Occupational Health Problems

Like most new industries that are vigorously expanding, this one has failed to make comparable progress in evaluating possible occupational health hazards. Historical examples of occupational health problems include the asbestos debacle, in which asbestos usage burgeoned without regard to evidence early in this century of associated health hazards.

The plastics industry expanded dramatically after World War II but with scant attention to occupational health. Later, angiosarcomas among vinyl chloride reactor vessel workers were a sobering reminder of past neglect.

Off-shore oil exploration has boomed at times of petroleum shortages. The very-deep diving required in this industry has produced anecdotal information suggesting serious long-term consequences of chronic sub-clinical decompression illness but almost no systematic study or standardized preventive measures.

Numerous additional examples could be cited. The main point is that new growth industries, beset by competitive pressures and industry "shake-out" and reluctant to miss out on growth opportunities, frequently relegate occupational health to a very low priority.

Some Do It Right

A different example of providing worker safety is found in the genetic engineering industry. A decade ago, before this field had been transformed from a research activity to an industry, there was great concern over potential health hazards. Many precautions and restrictions were placed on genetic engineering laboratories, most likely because the potential risk was perceived to extend beyond employees to the general public.

As a result, the evaluation of potential health hazards proceeded hand-in-hand with the development of the industry. Moreover, the required safeguards did not significantly inhibit the industry's growth. When experience had shown that the actual health hazards were not substantial, most of the precautions were rescinded.

UNCONTROLLED SITE HAZARDS

Today, there is an alarming lack of information on occupational health hazards related to uncontrolled hazardous waste sites. The USEPA contracts for approximately 500 medical evaluations per year of employees who work at such sites, and thousands more are evaluated in state and industry programs. Yet there are almost no published data on this topic. Nor are there data available on actual toxic exposures of personnel, results of biological monitoring or epidemiologic follow-up of employees.

USEPA Health Data

Examinations of approximately 150 USEPA employees by the Environmental Sciences Laboratory have not disclosed the presence of any significant disorders attributable to exposure to hazardous waste. A similar conclusion has been reached by Dr. Diana Ordin on the basis of approximately 450 examinations of employees of the New Jersey Department of Environmental Protection.

According to interviewed health and safety officers of the USEPA, there have been no hospital admissions for acute effects of toxic exposures among USEPA hazardous waste workers. Only one case requiring emergency room evaluation has occurred. There have been no burns, only a few minor cases of trauma and four or five incident reports. Only one complaint of a chronic skin disorder has been lodged.

Information of this sort is reassuring, but incomplete. It suggests that acute health hazards are uncommon among USEPA hazardous waste employees. It also suggests that most subacute disease developing over a period of weeks to a few years is uncommon.

Long-Latency Diseases

On the other hand, several categories of disease still cannot be ruled out with the information currently available. This includes long-latency diseases of many types, such as progressive organ damage leading ultimately to organ failure. Phenacetin-induced renal damage among analgesic users is an example from human toxicologic experience. Gradual cumulative damage to the kidneys, lungs, central and peripheral nervous system and liver are of particular concern. Long-latency carcinogenesis, of course, is another category that cannot be ruled out with current information. Even short-latency diseases cannot be ruled out if they are relatively asymptomatic and undetected by routine medical tests. Reproductive failures, behavioral abnormalities and immune dysfunction are prominent in this category.

Cardiac Disease

A final concern is the risk of sudden death due to cardiac disease. The working conditions of employees in uncontrolled hazardous waste sites increase the risk greatly. Protective clothing and equipment weigh as much as 55 lb for USEPA employees, not including loads of 50 to 100 lb that may be carried on occasion.

The impermeability of protective clothing creates an enormous problem of heat accumulation, particularly in unshaded areas. This problem is compounded by the difficulty in providing safe drinking water in such sites. Respirators with two or more "stacked" filtering cartridges greatly increase the work of breathing.

For all these reasons, deaths due to cardiac disorders may prove an even greater hazard to employees than toxic hazards. To date, there do not appear to be any recorded incidents of such deaths, although heat exhaustion has been quite common. This lack of problems is probably attributable to the fact that this new industry has mostly young employees. When there are substantial numbers of employees in their late forties and older, it seems almost inevitable that there will be cardiac deaths regularly, unless current practices are improved.

CONCLUSIONS

In summary, an examination of what little information is available suggests that much work remains to be done before there can be any complacency with regard to occupational health in the hazardous waste industry. The major areas requiring further work are:
•Characterization of the working environment (inside and outside of protective clothing);
•Biological monitoring of toxic substances and/or their metabolites;
•Medical surveillance carried out by physicians knowledgeable with occupational health problems and practices;
•Systematic, centralized review and analysis of findings; and
•Long-term epidemiological follow-up and analysis.

With regard to medical surveillance, current practices require supplementation to test for insidious disease processes with long latencies. In addition, cardiac risk factors must be evaluated in greater depth.

Such recommendations may appear excessive in a setting where there have been few documented health problems to date. However, one must remember problems (or lack thereof) that have occurred in other developing industries to appreciate the wisdom of this approach. It is likely that, after a number of years of such effort have been accomplished, only a few actual hazards will have been identified and numerous potential hazards found to be nonexistent. At that point, but only then, the medical surveillance program can be cut back to the efficient, focused effort seen in mature industries.

ASSESSMENT OF HUMAN HEALTH EFFECTS FROM EXPOSURE TO ENVIRONMENTAL TOXICANTS

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INTRODUCTION

On August 10, 1984, the House of Representatives voted on several amendments to House Bill HR5640, the "Superfund Expansion and Protection Act", as well as on the bill itself. One of the amendments called for the allocation of 12% of the $10.2 billion for compensation for medical care and lost wages to persons who had experienced adverse health effects which were "reasonably likely" to have been caused by exposure to hazardous wastes from one of the hazardous waste sites identified by the USEPA. Although the bill was passed, the amendment was defeated. One argument in opposition to the compensation amendment was that in the majority of cases the scientific means to establish whether an effect is the result of a putative exposure to a toxicant are not available.

A primary objective of the Clinical Chemistry Division of the Center for Environmental Health, Centers for Disease Control, is to develop methods to identify adverse health effects and to determine whether these effects are "reasonably likely" to have been caused by hazardous wastes.

Assessment of health effects of hazardous wastes must begin with a definition of what it is that is sought. What is an adverse health effect? Russel Sherwin of the University of Southern California School of Medicine has defined an adverse health effect as "the causation, promotion, facilitation and/or exacerbation of a structural or functional abnormality, with the implication that the abnormality produced has the potential of lowering the quality of life, causing a disabling illness or leading to premature death"[1]; stated briefly, the causation or abetting of an abnormality that can result in altered quality of life, disease or death. This definition stresses the very early stages of disease, the point at which there is potential for disease.

STAGES IN DEVELOPMENT OF ADVERSE EFFECTS

The progression from health to end points such as overt disease and death constitute a spectrum that can include an adaptive state, subclinical disease and the point at which adverse health effects are most commonly detected, symptomatic disease or death (Fig. 1). The insult, that is confrontation with the hazardous substance or its metabolite at the cellular level, can, and sometimes must be, present in the stages beyond the adaptive stage. Resolution of the insult can also occur at many points in this process.

Adaptation

Dr. Sherwin's definition might be qualified by saying that an event which is not an abnormality, but which may obtain the same results, is an adverse health effect. Some of the body's responses to stressful environmental factors, such as chemicals, are adaptive, helpful responses aimed at restoring a biochemical or physiological balance. These adaptive states often lead to the resolution of an insult without the host knowing that they have been challenged.

Although these responses are not abnormalities, there are cases in which this mechanism of adaptation can produce chemicals more dangerous than those with which the body was originally confronted. Cellular enzymes called mixed function oxidases (MFO) are bound to cell membranes that are called the endoplasmic reticulum in the intact cell and microsomes when isolated from the cell. The MFO metabolize endogenous compounds, such as fatty acids and steroid hormones, and lipophilic exogenous compounds, such as polychlorinated hydrocarbons and other xenobiotics, to more polar compounds that can be excreted or conjugated with other compounds, such as glucuronic acid, sulfates or gluthathione, and then excreted. Depending on the life-span of these polar metabolites of the MFO, they can bind to cellular macromolecules such as DNA, RNA or protein or initiate peroxidation of membrane lipids before they are further metabolized by conjugating enzymes. This formation of xenobiotic adducts with cellular macromolecules can ultimately result in cancer, birth defects, mutagenesis or other organ or system malfunctions.[2]

Enzymes which conjugate endogenous compounds, such as bilirubin and steroid hormones, and exogenous compounds, such as toxicants or their metabolites, are present in the endoplasmic reticulum with the MFO or in the cytosol. Enzymes of the MFO system and some enzymes of conjugation (such as glucronyltransferase and glutathione-S-transferase) are inducible: they are synthesized in response to the presence of their substrate, the compound that they metabolize. This property of induction by xenobiotics and the subsequent increase of products of these enzyme pathways is being investigated as supportive evidence for the presence of toxicant. D-glucaric acid is a urinary end-product of an inducible conjugation pathway, the glucuronidation/deglucuronidation pathway. In one study, elevated concentrations of D-glucaric acid in the urine of children living in an area contaminated with 2,3,7,8-tetrachlorodibenzodioxin (TCDD) correlated with the presence of chloracne.[3]
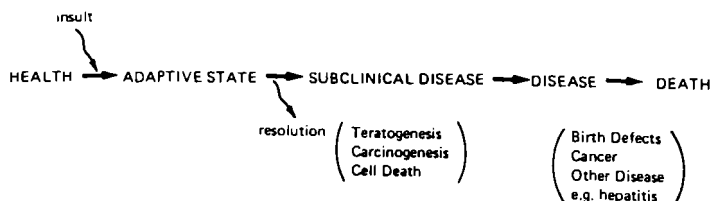

Figure 1
Spectrum of States Resulting from Toxic Exposures

If there is evidence that enzymes are being induced, is there also evidence of an adverse health effect? In some cases, the answer is yes and in others no. The primary determinants of toxicity are the amount and life-span of the intermediate. Other factors such as original dose of toxicant, route of entry and other host factors, not all of which are well understood, determine whether the metabolic product of enzyme pathways will be harmful.

Methods are needed to identify the adaptive phase and to be used in prospective studies to determine in which cases the adaptive phase signifies an adverse health effect. If induction of enzymes results in adduct formation with the toxicant or its metabolite and the process can be detected, intervention may be possible by administering chemical trapping agents that prevent binding to cellular macromolecules. Such intervention has been successful in ameliorating the toxic effects of poisoning with drugs such as acetaminophen.[4]

For the present, adverse effects must be detected beyond the adaptive state. Ideally, those at risk for adverse health effects should be identified using either actual body burden of toxicant or a surrogate measure of body burden. Within this selected group, a subgroup should be identified. In this case, an event that is closely associated with disease, but which occurs before subclinical disease, i.e., before there are biological changes in the cell causing altered cell function or cell death. Examples of such events are the binding of benzy(a)pyrene, or its metabolite, to DNA and the binding of TCDD to a receptor protein in the cytosol.[5,6] If these compounds could be identified bound to cellular macromolecules in accessible tissues (such as blood cells), placenta or scrapings of the mucous membranes, their detection in population studies would be feasible. Sensitive immunoassays which identify DNA-toxicant adducts in femtomolar concentrations have been developed and are of potential use in predicting risk for adverse health effects.[5]

Subclinical Disease

Subclinical disease is the point at which disease is an almost assured result without intervention. Biological and/or biochemical abnormalities and perhaps cell death are present at this stage. Symptoms are not apparent at this point. Biochemical markers, such as slight elevations in serum concentrations of enzymes due to altered cell membrane permeability, are being sought to identify this early stage of disease. A combination of measurements of alkaline phosphatase, bile acids and indocyanin green clearance can predict the presence of histological lesions in lungs of apparently asymptomatic persons exposed occupationally to vinyl monomers.[4]

Host Factors

The presence of a toxicant within a cell is evidence of exposure but does not always predict disease. Factors which are host-specific, which cause one person to be susceptible to the hazards of environmental chemicals and others to be resistant, will need to be evaluated to determine actual risk after exposure is documented by body burden or a biological effect. Host resistance depends largely on genetic factors. The innate competence of the immune system, the types and amount of enzymes produced and DNA repair when toxicant-adduct formation occurs, are genetically determined. Confounding environmental factors, such as poor nutrition or infection with hepatitus B virus, increase susceptibility.

METHODS FOR MONITORING HEALTH EFFECTS

Assays for assessment of adverse health effects have been organized into organ or organ-system categories by the Clinical Chemistry Division of the Centers for Disease Control. These categories include the liver, the kidney, the cardiovascular system and the immune system. It is true that the nervous and reproductive systems are targets for environmental toxicants. At present, however, there are no biochemical tests on accessible body fluid or tissue more sensitive than the methods used by the clinician in evaluating neurological function. There are certain assays that would give limited information about the reproductive system, such as chromosome rearrangement or DNA-toxicant adduct formation in sperm. These systems may be included at a later date.

Liver Profile

The liver profile consists of tests that were selected to reflect inductive or adaptive changes, damage to liver cells (hepatocellular damage) or impaired flow of bile (cholestatis), since bile flow is a major function of the liver (Table 1). The compounds with the suffix "ase" are enzymes, proteins which regulate the speed of reactions in the body. Beta-glucuronidase, gammaglutamyl transferase, alkaline phosphatase and glutathione-S-transferase are inducible enzymes and are included with the hope of detecting this early stage of induction. These four enzymes are also released in cell destruction and can be an indication of subclinical or overt disease.

Table 1
Liver Profile

Inductive or Adaptive Changes
    Urinary D Glucaric Acid
    Serum Gammaglutamyl Transferase
    Serum Beta Glucuronidase
    Serum Glutathione S Transferase (GST)
    Serum Total Bilirubin (Decreased)
    Serum Alkaline Phosphatase (5' Nucleotidase
      or Alkaline Phosphatase Isoenzymes)
    Urinary Mercapturic Acids
    Ratio of Oxidized to Reduced Glutathione in
      RBCs and WBCs

Hepatocellular Damage
    Serum Alanine Aminotransferase
    Serum Aspartate Aminotransferase
    Serum G S T
    Serum Total and Direct Bilirubin
    Serum Ornithine Carbamoyl
      Transferase (OCT)
    Serum Lactate Dehydrogenase
    Serum Sorbitol Dehydrogenase (SDH)
    Albumin/Globulin

Cholestasis (Impaired Formation of Canalicular
Bile or Its Exit)
    Serum Bile Acids
    Serum Total and Direct Bilirubin
    Serum Alkaline Phosphatase
    Serum Alanine Aminopeptidase

Additional Tests
    RBC Count and Indices

Although differentiating induction from release due to cell destruction can be difficult, the presence of enzymes such as aspartate aminotransferase and alanine aminotransferase, which are not inducible but which are usually elevated due to cell destruction, should help make this distinction.

With the exceptions of sorbitol dehydrogenase and ornithine carbamoyl transferase, these enzymes are not unique to liver cells. However, the liver is relatively enriched in most of these enzymes compared to other tissues. Alkaline phosphatase and lactate dehydrogenase are physically separated into components called isoenzymes which represent species coming from different tissues. 5'nucleotidase is a liver specific form of alkaline phosphatase that may help identify the source of the alkaline phosphatase that is elevated in serum.

Although these enzymes may definitively reveal neither which process, adaptation or destruction is occurring, nor in which tissue that process is occurring, when taken together in the context of other tests, they can provide evidence regarding the process and the site.

Cholestasis is a condition in which there is decreased bile flow and can result at the level of the hepatocyte following xenobiotic exposure. Enzymes that are present in serum in increased concentration due to cholestasis are alkaline phosphatase, 5'nucleotidase, alanine aminopeptidase and gammaglutamyl transferase.

As mentioned above, D-glucaric acid is an end product of the glucuronidation/deglucuronidation pathway and is excreted in urine. Elevated urinary D-glucaric acid concentrations are believed to be evidence of the liver's attempt to metabolize foreign or endogenous compounds.

Bilirubin is a breakdown product of hemoglobin which is metabolized and excreted by the liver in bile. Serum bilirubin concentrations are an indicator of liver function.
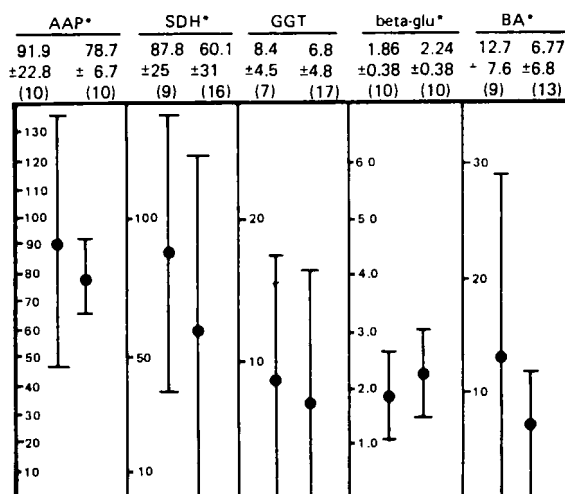
Mercapturic acids in urine are the end result of the binding of the highly reactive metabolites of xenobiotics to glutathione, a compound found in the cytosol of cells which acts as a trapping agent for these reactive compounds. When cellular glutathione stores are depleted, adduct formation can readily occur.

There is overlap in the classification of tests listed here. For example, when bilirubin is increased, there is usually either damage to liver cells and/or blockage of bile flow. When bilirubin is decreased, enzymes of conjugation have been induced and are causing bilirubin (an endogenous compound) as well as the toxicant (an exogenous compound) to be excreted with resulting lower blood concentrations. Bilirubin, therefore, is found in more than one category.

Four of these analytes have been quantified in male rats administered a single oral dose of 500 mg/kg of polybrominated biphenyls (PBBs) by gavage. Mean alanine aminopeptidase and sorbitol dehydrogenase concentrations from dosed rates were significantly higher than those of the controls (Fig. 2). Gammaglutamyl transferase concentrations were higher in PBB-dosed rates than in controls, but not significantly so. Mean beta-glucuronidase concentration from dosed rats was significantly lower than that of controls. Mean bile acid concentration was significantly higher in test animals. Interpretation of these data will follow completion of the other assays in the liver profile.

In a population at risk for exposure to TCDD, mean aklaline phosphatase, beta-glucuronidase and lactate dehydrogenase concentrations were higher in the total TCDD-exposed population than in a reference group matched for mean age, sex, alcohol and drugs (Table 2).[7] Mean gammaglutamyl transferase concentration distinguished persons with high blood PBB concentrations (>150 µg/l)[8] from those with low blood PBB concentrations (< 5 µg/l).[7] Additional animal and human studies are planned or are underway to determine which tests, or groups of tests, in this profile give pertinent information regarding exposure and health effects.

Serum alanine aminopeptidase, (AAP), sorbitol dehydrogenase (SDH), gamma-glutamyl transferase, (GGT), beta-glucuronidase, (beta-glu), bile acids, (BA) on rats dosed with 500 mg/Kg PBB (left) and controls (right). Mean values ± 2SD in figure, mean values ± 1SD above figures. Number of rats in parentheses

AAP*		SDH*		GGT		beta-glu*		BA*	
91.9	78.7	87.8	60.1	8.4	6.8	1.86	2.24	12.7	6.77
±22.8	± 6.7	±25	±31	±4.5	±4.8	±0.38	±0.38	± 7.6	±6.8
(10)	(10)	(9)	(16)	(7)	(17)	(10)	(10)	(9)	(13)

*Differences in means significant with P < 0.05.

Figure 2

Kidney Profile

The kidney profile includes four enzymes that are often elevated in urine after acute exposure to toxicants because of sloughing of cells lining the tubules of the kidneys (Table 3). These enzymes are gammaglutamyl transferase, lactate dehydrogenase, n'acetylglucosaminidase and alanine aminopeptidase. All of these enzymes are found in many tissues other than kidney, but elevated urinary concentrations can help to confirm an acute toxic insult. Many other enzymes have been demonstrated to be elevated in urine due to acute exposure. Four enzymes were selected; they were enzymes consistently reported in the literature as being useful.[9,10]

A relatively new, high resolution technique called two dimensional electrophoresis is used to identify and quantify proteins in

Table 2

Bilirubin, gammaglutamyl transferase (GGT), beta-glucuronidase, alanine aminotransferase (ALT), aspartate aminotransferase (AST), lactate dehydrogenase (LDH), alkaline phosphatase (Alk. Phos.), and triglycerides in populations exposed to PBBs and TCDD.

	Michigan			Missouri			Reference
	High PBB	Low PBB	All	High Risk	Low Risk	All	
	N=18	N=84	N=114	N=50	N=27	N=77	N=46
Bilirubin Direct (mg/dl)	0 17±0.2*	0.2±0.2	0.19±0.1	0.2±0.13	0.27±0.17	0.23±0.15	0.22±0.1
(0.0-0.5)‡	0.2†	0.2	0.2	0.2	0.2	0.2	0.2
Total (mg/dl)	0.51±0.2	0.54±0.2	0.54±0.2	0.58±0.3	0.68±0.35	0.61±0.3	0.45±0.2
(0.1 - 1.3)	0.4	0.5	0.5	0.5	0.6	0.6	0.35
GGT (mU/L)	25±26	15±21	16±22	16±21	18±24	17±22	17±9
(0-60, male; 0-45, female)	16	5	5	9	5	5	16
β-glucuronidase (u/L) §	2.18±0.8	2.24±0.94	2.24±0.95	2.78±1.13	2.43±1.03	2.66±1.1	1.91±0.82§
	2.00	2.04	2.03	2.56	2.27	2.37	1.78
ALT (SGPT) (mU/ml)	16±8	18±10	18±9	16±15	18±13	17±14	17±10
(5-40)	15	16	16	11	13	12	16
AST (SGOT) (mU/mL)	21±19	21±19	21±18	19±8	17±7	19±7	19±5
(10-40)	19	18	116	18	15	18	18
LDH (mU/mL)	173±50	161±44	163±45	172±31	180±25	175±32	151±28
(90-255)	154	155	154	175	172	170	144
Alk. Phos. (mU/mL)	46±11	52±15	51±15	63±24	64±31	63±26	47±12
(20-95)	44	49	49	62	56	57	46
Triglycerides (mg/dl)	103±48	123±62	120±60	107±55	105±64	107±57	94±44
(10-150)	95	120	116	90	77	88	88

*Mean values ± 1SD in u/L   ‡Reference limits

+Median values in u/L   §For the Reference Group: N=71

Table 3
Kidney Profile

Gamma Glutamyl Transferase
Lactate Dehydrogenase
N'acetylglucosaminidase
Alanine Aminopeptidase
Two-dimensional Electrophoresis
of Urinary Proteins

| 1 Application of protein to tube gel for separation based on charge | 2 Application of charge and separation of protein | 3 Tube gel placed across top of slab gel and protein are separated according to molecular weight |

Figure 3
Two Dimensional Electrophoresis of Proteins

body fluids; in this case, urine. Briefly, the method includes concentrating urine specimens and applying the concentrate to a cylindrical gel in a tube (Fig. 3). An electrical current is applied and proteins are separated according to their charge. This is the first dimension. The tube gels are then placed across the top of a flat, slab gel with increasingly smaller pore sizes. An electrical current is again applied and the proteins separate according to molecular weight. This is the second dimension. The slab gels are then stained with a sensitive silver stain and a pattern results. That pattern is interpreted using a computer-assisted imager. Rats dosed orally with PBBs as described above had protein patterns which were significantly different from those of controls (Figs. 4 and 5). Studies are planned to evaluate urinary protein patterns in human populations which have been accidentally exposed to toxicants. Generally, urinary enzymes are useful in detecting early injury to the renal tubules in acute exposures. Chronic toxicity more often results in nephrotic syndrome which is evidenced by increased concentrations of larger molecular weight proteins in urine.[1]

Cardiovascular Profile

The cardiovascular profile is a profile of blood lipids (fats) and proteins that are closely associated with them in the blood (Table 4). Because lipids are insoluble in the blood, they are transported as complexes with proteins which are soluble. Concentrations of these lipids and proteins have been used to determine risk for development of cardiovascular disease, hence the category cardiovascular

Figure 4
PBB-Dosed Rats
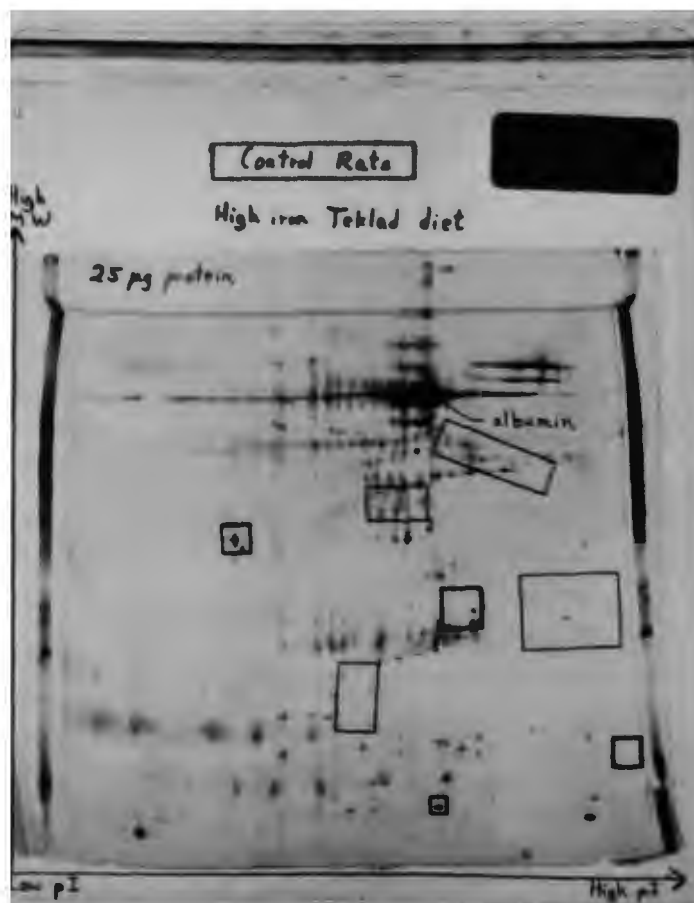
Figure 5
Control Rats

Table 4
Cardiovascular Profile

Cholesterol
Triglycerides
HDL-Cholesterol
Apolipoprotein A-1
Apolipoprotein A-2
Cholesterolester Fatty Acid Composition
Phospholipid Fatty Acid Composition

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system. Blood concentrations of cholesterol, triglycerides and high density lipoprotein-cholesterol (HDL-cholesterol) are known to be altered by certain toxicants, possibly as an indirect result of liver dysfunction.[12] Alterations in concentrations of two lipid-associated proteins, apolipoproteins A-I and A-II, are being investigated in toxic exposure.

Fatty acids are long chain hydrocarbons with a carboxyl group through which they may covalently bind to other compounds (such as phosphoglycerides), forming phospholipids (important components of cell membranes).

Rats given a single oral dose of 500 mg/kg PBBs were sacrificed at intervals of from 1 to 8 weeks. They had alterations in microsomal membrane phospholipids when compared to controls (Table 5). Mean liver weight in the PBB-dosed rates was higher than that of controls (Table 6) which is consistent with the proliferation of the lipids and proteins of the encoplasmic reticulum during an adaptive phase.[13]

Immune Profile

The immune system is a complex interaction of many types of white blood cells, tissues, hormones and other components. It is difficult to pinpoint an abnormality in the immune system without extensive testing. There are basically two types of immunity; cell-mediated and antibody-mediated or humoral immunity. These two types of immunity can be assessed separately, although they are often interdependent. Cell-mediated immunity is dependent on lymphocytes (white blood cells) called T-cells, and antibody-mediated immunity is dependent on lymphocytes called B-cells.[14]

Adverse effects of toxicant exposure include suppression of cell-mediated immunity, which protects against development of cancer

Table 5
Immune Profile

White Blood Cell Count with Differential Smear
  T-cell Profile
    T-helper
    T-suppressor
    Null Cells
  T-cell Function (Proliferation Tests)
    Phytohemmagglutinin
    Concanavalin A
    Pokeweek Mitogen
  B-cell Profile
    Serum Immunoglobulin Concentrations
              IgG
              IgA
              IgM
    Skin Tests
      Tetanus Toxoid
      Diphtheria
      Streptococcus
      Tuberculin
      Candida
      Trichophytin
      Proteus

Table 6
Effect of Polybrominated Biphenyls on Hepatic Microsomal Fatty Acid Composition

Fatty Acid	PBB-Dosed $(X \pm SEM)^{Wt \%}$ (n = 15)	Control $(X \pm SEM)$ (n = 8)
14:0	0.31 ± .02	0.59 ± .05
16:0	15.40 ± .18	23.50 ± .87
16:1 (n—7)	1.49 ± .14	3.32 ± .25
18:0	26.93 ± .59	19.07 ± .31
18:1 (n—9)	11.84 ± .82	7.08 ± .16
18:1 (n—7)	2.94 ± .17	3.99 ± .29
18:2 (n—6)	9.54 ± .31	12.07 ± .45
20:3 (n—6)	0.86 ± .04	1.16 ± .11
20:4 (n—6)	25.87 ± .51*	23.83 ± .60
22:4 (n—6)	0.43 ± .04 (NS)	0.36 ± .06
22:5 (n—6)	0.46 ± .06 (NS)	0.35 ± .05
22:5 (n—3)	0.44 ± .03 (NS)	0.51 ± .03
22:6 (n—3)	3.01 ± .17	4.13 ± .35

$*p < .05$
NS = not significant
All others: $p < .01$

N is the number of microsomal preparations. Each preparation was obtained from two pooled livers. All of the exposure periods were combined for this comparison. Trivial names for the first nine acids given in this Table are: myristate (14:0), palmitate (16:0), palmitoleate (16:1, n—7), stearate (18:0), oleate (18:1, n—9), cis-vaccenate (18:1, n—7), linoleate (18:2, n—6), dihomo-γ-linolenate (20:3, n—6) and arachidonate (20:4, n—6).

Table 7
Hepatic Weight Response to a Single Oral Dose of Polybrominated Biphenyls

Weeks	Liver Weight[a] (g)	% of Body Weight
1	22.13 ± 1.20 (8)	4.47 ± 0.21 (8)
2	22.32 ± 1.37 (8)	4.51 ± 0.20 (8)
4	23.35 ± 0.89 (8)	4.70 ± 0.12 (8)
8	26.13 ± 1.35 (7)	4.94 ± 0.21 (7)
Control[b]	14.81 ± 1.37 (4)	2.88 ± 0.80 (4)

[a]All values are x ± SEM; the number of animals for each group is given in parentheses.

[b]Four-week data only.

and viral infections, and may include abnormalities in antibody-mediated immunity, which protects us from bacterial infection.[15,16] In testing for immune function, total numbers of lymphocytes are determined and the ratios of subgroups of T-cells (T-helper and T-suppressor cells) are determined (Table 7). These cells are also tested to determine if they are functional by exposing them to foreign compounds called mitogens, which stimulate cell division. This method is called mitogen stimulation testing. There are many other components of cell-mediated immunity, but T-cell function is the principal component for understanding this function of the immune system. B-cell immunity can be evaluated by determining antibody concentrations in serum.

CONCLUSIONS

A wide variety of assays that may help assess health effects by determining whether a person or population has a toxicant burden, whether an event has occurred that increases their risk for disease (the binding of toxicant or its metabolite to cellular macromolecules) or whether there is a biochemical or functional abnormality that may be a result of exposure to a toxicant has been enumerated. This group of assays will be evaluated for use in

assessing health effects. Statistical methods enabling us to recognize patterns of test results which correlate with body burden of toxicant or inapparent histological changes are in place to help evaluate these assays. Present technology allows determination of the concentration of a toxicant in the environment and, in many cases, the body burden of the toxicant or its metabolite. The link between these events and overt disease is elusive. A combination of controlled prospective animal, clinical and epidemiological studies will establish these relationships. Until these studies are complete, relative risk for development of disease, time sequence of exposure and development of disease, knowledge of a biological mechanism that could explain the relationship (as is the case for high-cholesterol diets and heart disease) and other epidemiological criteria are evidence of cause and effect relationships.

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THE MEDICAL SURVEILLANCE OF HAZARDOUS WASTE WORKERS

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INTRODUCTION

The publicity given to Love Canal, dioxin contamination and chemical spills in emergency situations, has focused attention on the dangers of hazardous wastes. All too common are pictures of people leaving, or wondering whether to leave, their homes while workers in "moon suits" use exotic testing equipment to evaluate the hazard or cleanup a site.

These situations have brought new challenges to health professionals because of the unconventional types of exposures, both actual and potential, and the inability to clearly define the expected effects. This complex challenge is particularly important to the occupational health professional who must deal with the workers that are cleaning up these waste sites.

In this paper, the author describes some of the problems involved, and addresses the provision of medical surveillance to these workers.

PROBLEMS FACED

Even those trained in occupational or environmental medicine are usually not prepared for the complexity of the problems at these sites. A typical abandoned waste site will be:

In a rural, probably wooded, area. Thus, it is out of the way and out of sight of law enforcement officials. There are hundreds, perhaps thousands, of drums in varying states of deterioration. There may be a few labels on some of the drums that list contents but, because of their condition and age, there is no way of knowing whether the labels have any relation to the current contents. Some leaks appear to be oil and may indicate the presence of PCBs. Since many drums seem to have some connection with pesticides, there may also be dioxins present.

There are several humps in the area that with only a little digging reveals more drums, forcing extensive excavation. There are also a few abandoned truck trailers containing both liquids and solids.

In the typical case, there will also be multiple sources of potential contamination to nearby residents: a stream running through the area feeding into a river near a city's water supply; a children's summer camp; or signs of past fires. These raise fears of direct contact. When odors are present, they suggest the presence of volatiles with the attendant air contamination.

This description is only exaggerated to the extent that all the features are thrown together. It is not unusual or atypical.

Here is another situation:

A ship going down a river has hit a bridge abutment which was supporting a train with a number of tank cars and boxcars all holding various chemicals. At least two of the cars have fallen into the river below and broken open. Several of the cars still on the bridge and just beyond its confines have also broken open and are leaking. There are what are described as fumes above the river, and a multi-colored plume is moving down stream. A cloud is rising above the wreck site and there is a small fire beginning.

These two situations, while vastly different in many ways, are alike in that both must be evaluated and cleaned up, and the workers must have a reasonable chance of doing that work without injury or illness.

EMERGENCY MEDICAL ADVICE

The time pressures of the emergency situation do not relieve the physician of the necessity of giving advice that will: (1) protect the workers, and (2) allow the cleanup work to proceed efficiently.

However, there will never be enough information; one always wishes to know more. In most cases, one will not know all of the substances present and even less about what mixtures may have been formed and what their toxic effects might be. Other unknowns might include what water might do to the chemical's toxicity or whether sunlight and variable climatic conditions cause an increase in toxicity.

As they sit for years in drums, do some chemicals, normally stable, become unstable and dangerous if shocked or jarred? A constant danger is that many compounds, the organophosphate pesticides, for instance, are very efficient skin penetrators. So are most of the solvent materials that are ubiquitous at hazard waste sites.

There are many useful databases available for these situations, but not one ideal. Many of the questions are unanswerable because no one knows what happens under some of these circumstances. Thus, one frequently must take what is known or what can rapidly be obtained, make quick mental extrapolations and then formulate advice and recommendations as to the personal protective equipment and special procedures needed by workers at the site.

Obviously, the protection of workers takes on a slightly different character than is found in the usual industrial situation.

MEDICAL APPROACHES

As with any medical issue, there are different ways of looking at the situation. Two extreme approaches will be examined which I will label the "Do-Everything" or "Do-Nothing" view.

Do-Everything

The Do-Everything approach is based on the assumption that baseline tests should be carried out for as many substances as are technically feasible. This approach also suggests baseline tests of as many organ systems as possible to allow a comparison, if exposure occurs, to determine the presence of harmful effects.

There are problems with this approach. Besides the obvious, enormous expense of such testing, there is the time that the worker is off the job and the resulting loss of productivity. An employee of the USEPA or one of the more active private contractors doing this work may be involved in dozens of different sites each year, each with its unique situations. It is difficult, if one believes in this approach, to pick a frequency of testing that will allow the kind of close watch that is desired. Another major problem with this approach is the very practical one of finding qualified and competent laboratories and medical professionals within a reasonable distance and able to do the testing required.

Do-Nothing

The Do-Nothing view maintains that only those tests which will show that a worker is in good general health should be carried out

and that continual emphasis on training and proper work procedures be maintained. When an exposure occurs, the toxicity of the substance or the situation is evaluated and appropriate, specific testing is carried out to determine if any adverse effects have developed.

With time, I have come to lean toward the latter, or Do-Nothing school of thought, although I would prefer that it be labelled the "Do-A-Little-Bit, Well" approach. Here is my reasoning:

First, the chances are significant that, even with an attempt to measure everything, the substance to which an exposure actually does take place will not have been measured in the base-line tests. Second, there is no chance whatever that the combinations and mixtures of substances can be directly evaluated. Third, there is the tendency of multiple-testing programs to give a false sense of security to both the workers and the physicians responsible for them. Finally, there is the very significant expense of the testing.

A problem with the do-nothing approach is that little tangible evidence is given to the worker or his employer that his health is, in fact, being monitored.

What, then, is suggested as a medical surveillance program?

SURVEILLANCE PROGRAM

A worker new to hazardous waste work should have a pre-placement examination consisting of a complete and detailed occupational and medical history followed by a thorough physical examination made available to him. Emphasis during the physical should be placed on overall physical fitness and suitability for heavy manual labor with a variety of tools and equipment and the ability to wear and utilize a large variety of personal protective equipment including SCBA and fully encapsulated suits. Vision tests and pulmonary function testing, including, as a minimum, the FVC and the FEV, are important.

Although I feel that the utility is very limited, a postero-anterior chest X-ray may be useful for comparison or baseline purposes.

Since many of the substances encountered are hepato-toxic, a multi-channel blood chemistry can be done, if available, since it is often cheaper than individual tests, is widely reproducible and contributes a nice range of information.

If it is known that a strong potential for exposure to organophosphate pesticides exists, it may be worthwhile to perform a baseline serum and/or red blood cell cholinesterase. Likewise, if other particular substances are known to be present and the exposure at that site will be of long duration, baseline tests specific to them can be utilized.

Other laboratory work-up is limited to a complete blood count and urinalysis (with microscopic).

The history should be updated yearly to determine if any exposures may have had the potential for adverse effects. A brief physical is also appropriate as is a repeat of the pulmonary function test. If desired, the blood work can also be repeated. If a part of the program, the chest X-ray can be repeated perhaps every four to five years.

As you can see, my suggestions are quite variable and very site-specific, but I believe that they will allow the responsible physician to maintain a reasonably close view of the worker's health with a minimum in outlay of both funds and productivity of the employee.

MEDICAL EMERGENCIES

For the emergency situation, there are several things that usually demand consideration at the same time: the effects that may be occurring to those first responders (usually fire or police personnel); the workers brought in to perform the cleanup; effects to those involved with the incident itself, but close-by and thus subject to its effects; and finally, some peripheral issues concerning "incidental" personnel such as reporters, etc., and requests from hospitals and local health departments for assistance.

These situations are almost always chaotic, particularly in the early hours. Information is scarce, and the data that arrive are sometimes contradictory. If some people on-site are overcome, this situation creates more concern and the local medical care facilities may be overwhelmed.

If one tries to wait for all of the desired information to arrive, a long time can elapse with resultant unnecessary adverse health effects to the personnel involved. Therefore, as noted above, one must act on what one knows, and make recommendations for protective equipment, work practices and evacuation on the best available data; however, one must also be prepared to change those recommendations, perhaps radically, when new data arrive.

When making treatment recommendations, there are relatively few chemicals(cyanide or certain pesticides, for example) requiring specific and/or immediate therapy. For most, symptomatic and supportive care will serve the patient well until better information becomes available. This advice makes emergency room personnel more comfortable, since they tend to assume that every chemical involved in an environmental incident requires specific and perhaps exotic, care. There is time, in most cases, for specialized care to be instituted after the emergency has calmed down a bit.

It should be mandatory that patients treated and released be told to keep close awareness of their physical condition, particularly the pulmonary system, for a period of 72 hours and to report to medical facilities if changes are noted.

Contrast with Industry

In contrast to the usual industrial situation where workers use known specialized equipment, techniques or substances and have special testing or examinations specifically tailored to their potential exposures or duties made available, the working environment of the hazardous waste worker is more difficult to define. In industry one can, if necessary, work backward and discover those substances or conditions to which the workers may have been exposed. There are always many things one does not know, but there is usually a place to begin. In the hazardous waste situation, this may not be true.

When wearing the fully encapsulated "moon suit" and utilizing SCBA, the worker is also clumsy and unable to move quickly, thus creating a potential for trauma-producing accidents. It is widely accepted that far more injuries on hazardous waste sites are caused by accidents than by chemical exposures.

Weather

Since it is obvious that most cleanup takes place outdoors, the weather plays a large role. The toxicities of the substances can vary; cold weather, for example, reduces vapor pressure and there is less tendency for substances to volatilize; heat causes the opposite effects.

Extreme heat or cold creates worker stress, as in any out-of-doors employment, but temperature is an extra problem to the hazardous waste worker primarily because of the extensive protective equipment that he must wear. In summer, significant heat loads are generated quickly because of the impervious clothing utilized. The workers on the site and their supervisors must be familiar with the signs and symptoms of heat stress and know the appropriate first aid procedures.

CONCLUSIONS

In summary, the hazardous waste program in the United States is one that presents many fascinating challenges to the occupational physician. Meeting those challenges requires an ability to innovate and make decisions quickly if the workers are to have the protection to which they are entitled.

DISCLAIMER

The opinions expressed in this paper do not represent official NIOSH or ATSDR policy and should in no way be taken as an official position of the U.S. Government. They are the author's viewpoint developed through experience with these situations; one that he has found to be useful.

MULTIPLE CHEMICAL EXPOSURE CONSIDERATIONS ASSOCIATED WITH HEALTH AND SAFETY ASSESSMENTS

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INTRODUCTION

Multiple chemical exposures exist in many industrial and environmental situations, but the problems associated with enhanced toxicity (toxic interactions) due to combined exposure are often ignored. Hazardous waste sites present a worst case potential in this regard due to the multitude of different chemicals often found at a single site. The possible combinations are enormous and largely unpredictable. In this paper, the author discusses a set of principles governing toxic interactions which can be used to recognize and evaluate the potential hazards of waste sites by those responsible for employee health and safety and by those conducting health risk assessments. Although interactions between two chemicals can lead to decreased toxicity, only the concern of increased toxicity is discussed.

Toxic interactions are manifested by an effect on one or more of the major physiologic processes that determine how the body handles foreign materials.[1] These processes are the absorption, distribution, biotransformation and excretion of chemicals. This section is followed by a discussion of recommendations on how to manage the risk of toxic interactions once the potential hazard of a multiple chemical exposure is known.

BASIC CONCEPTS

Simplified, toxic interactions can arise by the two general mechanisms of addition and potentiation. Additive interactions are more easily conceptualized. For example, many chemicals such as chloroform and diethylether cause central nervous system depression manifested by the typical inebriating effects of uncoordination and light-headedness. A specified exposure to any one of these agents may cause slight or no detectable adverse effects. However, if one was exposed to several of these agents simultaneously, dizziness or some other effect could ensue even though the exposure concentrations of the individual chemical components were the same as when the person was exposed to that chemical alone with little or no effect. This type of interaction is usually additive. That is, the combined effect is equivalent to the sum of the effect when each agent is given alone. In the exceptional circumstance when the combined effect is much greater than that predicted from the sum of the two, this is referred to as synergism. The mechanisms behind many synergistic interactions are unknown.

The toxic interactions termed potentiation are situations where one substance does not cause a certain toxic effect, but when combined with another substance that does cause that effect, the toxicity is greatly enhanced. For example, isopropyl alcohol is not toxic to the liver while carbon tetrachloride is hepatotoxic. When these
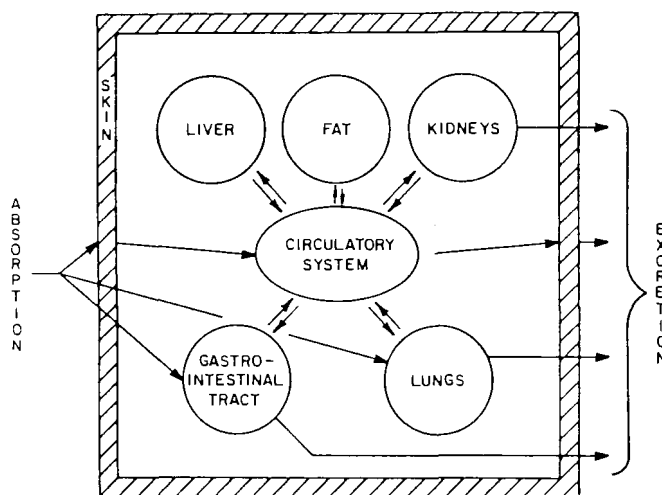
Figure 1

Schematic representation of the body showing how the different organ systems interact in the processes of absorption, distribution, biotransformation and excretion.

two materials are combined, the hepatotoxic response to exposure is much greater than when carbon tetrachloride is given alone.[2] This interaction has been documented in man as a result of an industrial exposure to both agents.[3]

A brief overview of the dynamic processes involved in how foreign materials are absorbed, handled and excreted will help provide a background for understanding how toxic interactions of potentiation occur. Figure 1 contains a schematic representation of the body and some of its components. Exposure to a chemical can occur by various routes such as skin contact, ingestion and inhalation.

In these cases, the layers of skin, lining of the gastrointestinal tract and membranes in the lung serve as barriers between the chemical and the general circulation. Crossing these barriers is referred to as absorption. Once a chemical gains access to the blood, it is distributed to organs throughout the body by the circulatory system. As shown in Figure 1, some organs actively eliminate chemicals from the body: the kidneys via urinary excretion, the digestive system via fecal excretion and the lungs via gaseous exhalation.

If a foreign compound is not readily excreted in its parent form, the body is capable of transforming the chemical, usually rendering it more water soluble, so that it is more easily excreted. This process of biotransformation is a major function of the liver.

These processes of absorption, distribution, biotransformation and excretion can be affected by the toxic actions of one chemical exposure in a manner making the body more susceptible to other chemicals during the same time period of exposure or in a subsequent exposure.

This is the basic concept that accounts for most instances of potentiation and explains some examples of synergism. Most of the published literature addressing toxic interactions involve studies on pharmaceutical agents, while little specific information in this regard exists on industrial chemicals. As much as possible, this paper describes the few studies describing toxic interactions among industrial chemicals relevant to the hazardous waste industry.

RECOGNITION OF POTENTIAL TOXIC INTERACTIONS

Additive Interactions

Potential additive interactions are easier to recognize because they usually involve substances that share the same target organs for toxicity. All organ systems are potential targets of toxic interactions caused by multiple chemical exposures. Particularly susceptible, though, are the respiratory tract as the major route of occupational exposure, the liver as the principal organ in the biotransformation of foreign compounds and the kidneys as the predominant route of foreign compound excretion.

Candidates for additive interactions involving acute lung injury and chronic pulmonary fibrosis are: acid fumes and other pulmonary irritants such as the metal fumes of cadmium, beryllium and aluminum; fibrogenic dusts such as asbestos and silica; and oxygen in abnormal concentrations.[4] The liver is sensitive to many chlorinated hydrocarbons including polychlorinated biphenyls (PCBs) and chlorinated dibenzofurans (structural analogs to dioxins), which are extremely toxic and are commonly found as contaminants of PCBs. The kidneys are also sensitive to several chlorinated hydrocarbons (i.e., chloroform and carbon tetrachloride) and heavy metals (i.e., mercury and chromium).

Potentiation Interactions

Absorption as a site.

Occupational poisoning cannot occur without absorption of a toxicant. Any chemical exposure affecting the barriers to absorption by making them more permeable is a candidate for potentiating the toxicity of other chemical exposures by enhancing the quantity of those chemicals absorbed. For example, the skin, due to its thickness and structure, poses a significant barrier to penetration by chemicals, especially those that are water soluble (hydrophilic). However, a damaged skin is more readily penetrated by both hydrophilic and lipophilic (fat soluble) substances. Therefore, washing the hands with organic solvents (i.e., thinners and gasoline) or with abrasives which damage the skin increases the risk of skin penetration by other toxic substances. Similarly, surfactants used as foaming, dispersing, wetting, detergent and emulsifying agents and phenols disintegrate cellular membranes in the skin and decrease the skin's ability to limit the absorption of foreign compounds.

The skin is an important route of occupational exposure, but the respiratory tract is the major pathway. The lung is designed to facilitate rapid absorption due to its function of gas exchange, so there is little that can happen which would further enhance its permeability. Gardiner and Schanker[5,6,7,8] showed that rats inhaling acidic fumes, paraquat, aerosolized palain and rock dust all suffered irritancy and damage which appeared to increase the porosity of the pulmonary epithelium and enhancing absorption. Also, ciliated cells in the respiratory airways help keep the lungs clear of foreign particles. There are agents, such as formaldehyde and cigarette smoke, which strongly inhibit this ciliary action of bronchial epithelium which reduces the efficiency of particle removal. Consequently, there is an increase in the quantity of particles retained in the lung and a potential increase in the amount of foreign material absorbed from within or on those particles.

Biotransformation as a site.

This is probably the most common site for toxic interactions due to the phenomena of enzyme inhibition and enzyme induction. Literally all foreign compounds are subject to biotransformation by enzyme systems which are primarily located in the liver but are present to some extent in all organs of the body. Biotransformation reactions usually detoxify foreign compounds and make them more readily excreted.[9] However, it is common for these reactions to form toxic intermediate or end products (metabolites) that are more toxic than the parent materials comprising the original exposure. Therefore, any alteration in the enzyme systems responsible for biotransformation, either inhibition or induction, can cause a toxic interaction depending on the nature of the materials involved in the multiple chemical exposure.

Unfortunately, most of the studies that have been conducted on toxic interactions involving biotransformation have been designed to elucidate mechanisms and have not been conducted by routes of exposure or at dose levels that resemble "real life" circumstances. Also, therapeutic agents and not industrial chemicals are those most frequently studied. A few illustrative examples pertinent to industrial chemicals are given in this paper and the interested reader is referred to a couple of exhaustive reviews.[10,11]

Enzyme inhibition leads to toxic interactions by slowing the rate at which a toxic foreign compound is metabolized, thereby increasing the systemic exposure to the parent material. Since metabolism of a chemical facilitates its excretion from the body, biotransformation inhibitors also increase the residence time of other foreign substances in the body.

Two chemicals may inhibit one or the other's biotransformation by competing for the same limited enzyme. This is true of short-chain alcohols and glycols which are all metabolized by alcohol dehydrogenase. Some of the best inhibitors of biotransformation enzymes are those that undergo little or no metabolism, such as the perfluorinated hydrocarbons. Other compounds are commercially important specifically because they inhibit metabolism and, thus, augment the activity of insecticides. The 1,3-benzodioxles are the best examples; butoxide is the most commonly used.[12] Other important inhibitors are sulfur-containing compounds, such as carbon disulfide and the phosphorothionates[13] and some nitrogen-containing compounds, such as the imidazoles.[14]

Enzyme induction can cause toxic interactions by increasing the rate at which a non-toxic foreign compound is converted into a toxic form. Many of the most effective enzyme inducers are aromatic chlorinated hydrocarbons with prolonged biological half-lives (i.e., slowly excreted from the body). These include the chlorinated insecticides and PCBs. The chlorinated dibenzodioxins and dibenzofurans are the most potent inducers known. Other well documented inducers include the polynuclear aromatic carcinogens and certain drugs, most notably phenobarbital.

Another important feature of biotransformation enzyme induction is its onset and duration. The inducing action of different compounds begins at different rates and continues after cessation of exposure for various lengths of time. The time after exposure when maximum induction occurs varies from one day for 3-methylcholanthrene to approximately 2 weeks for the insecticide chlordane.[15] The duration of induced enzyme activity can be from days to months after the last exposure.

Elimination as a site.

Renal elimination is the major route of excretion for many foreign compounds. Any intoxication which interferes with this process has the potential for causing a toxic interaction by allowing the accumulation of chemicals in the body during a combined exposure or during an exposure subsequent to the renal injury. The glommerular membrane of the kidney is extremely porous and

allows all but the high molecular weight materials, such as proteins, to pass through. The subsequent tubular epithelium is a lipoprotein barrier where water and specific materials, for example electrolytes, are reabsorbed. The metabolities of foreign compounds are usually not reabsorbed but pass on into the urine unless the tubular membrane is damaged. Nephrotoxic agents which damage the proximal tubular epithelium include short chain chlorinated hydrocarbons (chloroform, carbon tetrachloride) and certain heavy metals (mercury, chromium, uranium).

MITIGATING FACTORS IN TOXIC INTERACTIONS

Several factors can make toxic interactions more likely to occur. These include preexisting disease states of the liver, kidneys and lungs which would make a person more susceptible to the many toxic effects that lead to toxic interactions. Prescribed and abused drugs, such as alcohol, are difficult to control and monitor, yet these have a high potential for being involved in an interaction. Whereas occupational exposures are carefully controlled to prevent any detectable toxic effects, drugs are taken deliberately in quantities high enough to elicit an altering effect. For example, phenobarbital at therapeutic doses is a potent inducer of biotransforming enzymes, an effect that may cause a toxic interaction. Also, Elovaara et al.[15] showed that inhalation of xylene when coupled with ethanol ingestion produced severe liver damage, while independent exposure to xylene or ethanol failed to do so.

MANAGEMENT OF RISKS TO INTERACTIONS

Toxicity due to occupational exposure is generally manifested only during episodes of abnormally high exposure concentrations. Most industrial hygiene programs limit occupational exposures to a very significant extent, thus greatly reducing the potential for toxic interactions. Their consideration is nonetheless important, especially in circumstances where operations are being conducted at or near the occupational exposure limits, and/or the multiple chemical exposure will occur over an extended period of time. Several recommendations given below should help control the risks to toxic interactions resulting from multiple chemical exposures. Depending on the sophistication of a company's industrial hygiene program, these may be incorporated into existing activities without any additional costs.

Evaluation

Each situation involving multiple chemical exposures should be evaluated for the potential of a toxic interaction in view of the principles discussed in this paper. Depending on the chemicals involved, this will require seeking out additional information and referring to more sources than would otherwise be necessary. The chemicals should be categorized by their routes and projected magnitudes of exposure, target organs for toxicity and potential to alter the biotransforming enzyme systems. Input should be obtained from a toxicologist, if possible.

The time required for this qualitative assessment is more justifiable on a cost-effective basis for circumstances where the multiple chemical exposure is routine and the same substances are consistently involved. For situations where the exposures are constantly changing, the evaluation is an on-going process and more time consuming but just as important as in the case of the more routine work conditions. If such evaluations are not possible, then a very conservative approach should be taken toward protecting workers against exposure.

The American Conference of Governmental Industrial Hygienists[16] has developed a threshold limit criterion for chemical mixtures and multiple chemical exposures. The quantitative approach described is adequate for circumstances where there is no interaction or where the interaction is additive. However, the approach may not be adequate to control potentiation interactions, and the mathematical manipulations should be adjusted accordingly depending on the details of the particular situation.

The NAS (1980) proposed a quantitative method for compensating for known instances of toxic interactions. However, this requires sufficient health effects data to quantitate the potentiation, and only in exceptional circumstances will such data be available. In most cases, adjustments in the limits to exposure deriving from concerns over possible toxic interactions can be made only through a subjective evaluation.

Medical History and Monitoring

Many companies in the hazardous materials industry already have occupational medicine programs that include obtaining detailed medical histories and obtaining periodic medical exams. These records should be consulted when individuals are assigned to different work projects with the potential for chemical exposure, and the accuracy of the information should be checked with particular attention given to prescription medications and chronic illnesses. Incorporation of medical monitoring into work plans should be considered when the proposed work activities will involve extremely toxic materials.

Training

Education on the importance of an accurate medical history, including the use of prescription medications, should be incorporated into the company's health and safety training program. The necessity of occasional medical monitoring for certain work assignments should be explained to employees. This step will aid in obtaining employee cooperation and will decrease the chances of alarm when a situation requiring monitoring is encountered. Employees should be made aware that the exposure scenario will be re-evaluated when new chemicals are introduced into their work activities.

Workplace Monitoring

Sufficient work area monitoring of chemicals should be conducted to ensure that exposures to multiple chemicals are not higher than anticipated. The results from monitoring operations should be reviewed frequently to detect changes. If new chemical substances are introduced into the occupational environment, the situation should be reevaluated with consideration given to the potential for toxic interactions.

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CONTROL OF FUGITIVE DUST EMISSIONS AT HAZARDOUS WASTE CLEANUP SITES

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INTRODUCTION

Spills, waste disposal and various industrial operations can result in the contamination of land surfaces by toxic chemicals. Soil particles from these areas can be entrained into the air, transported off-site by the wind and result in human exposure by direct inhalation. Indirect exposure could result if particulates are deposited in agricultural fields, pastures or waterways and thus enter the human food chain. Since many environmentally troublesome compounds are tightly bound to particles, and many surface-contaminated sites have conditions favoring wind erosion, such as sparse vegetation cover and high levels of activity which disturb the surface, this exposure route is important.

Contaminated soil can be entrained by the air in three basic ways:
• Wind erosion
• Reentrainment by moving vehicles (rubber-tired or tracked vehicles) on soil or paved/unpaved roads
• Active cleanup (movement of soil by dozers, loading by front-end loaders, etc.)

These three mechanisms can act individually or in combination.

Dust control at a hazardous waste site is a different problem than control of non-contaminated dust to improve particulate air quality. While 50 or 75% control of dust from an unpaved road might be adequate for air quality purposes, it is not adequate for contaminated dust. Any direct or indirect human exposure to contaminated soil is potentially harmful; 100% control is the desired goal.

Very little information is available to assist in developing dust control programs at cleanup sites. Field testing of dust control effectiveness has been limited to vehicle-caused re-entrainment of dust from paved and unpaved roads. The purpose of this project was to:
• Perform field demonstrations of several products to determine their effectiveness for controlling dust
• Prepare a handbook on state-of-the-art methods of dust control

Three field studies were performed. In these studies, 14 dust suppressants were tested to determine their effectiveness in controlling fugitive dust against wind erosion from exposed areas. The second wind erosion field study was an evaluation of the effectiveness of windscreens, and windscreen/dust suppressant combinations, in controlling fugitive dust from storage piles. The third field study, investigating active cleanup emissions, consisted of testing fugitive dust control measures applicable to loading dirt by front-end loader into a truck.

A *Dust Control Handbook* was prepared. For each of the three basic re-entrainment mechanisms, the following were described:
• Identification of dust producing points
• Principles of control
• Product listing by name, address, telephone number, dilution, application rate, basic application method and cost
• Detailed application procedures
• Product effectiveness

DATE COMPILED

Control of Wind Erosion Dust Emissions from Exposed Areas

The objective of this study was to identify dust suppressant methods that are 100% effective in controlling wind erosion emissions. This criterion allowed flexibility in designing the sampling protocol since no control efficiency or emission rate data were required. The answer could be, "yes," the dust suppressant is 100% effective, or "no," it is not 100% effective.

Although several approaches were available for testing wind erosion emissions, tracer sampling was chosen as the methodology most closely paralleling the requirements of this study. In order to determine the effectiveness of a dust suppressant in controlling fugitive emissions from an exposed test plot, it is necessary to detect particles leaving the plot. This may be done by capturing airborne particles. To overcome the problem of determining the origin of the loose material, a tracer was added to the soil of the test plot. The tracer was mixed with the soil before a commercial dust suppressant product was applied to the surface. Any tracer-laden particles later found in the ambient air around the test plot indicated a failure in the integrity of the crust formed by the dust suppressant.

The test plots were located on a small farm near Cincinnati, Ohio. The plots were located several hundred feet apart to eliminate cross contamination of tracer between plots. The plots were prepared by removing vegetation from 50 ft x 50 ft areas with a bulldozer and grading the plot smoothly. One of two different tracers was applied to each bare plot. Zinc oxide (water insoluble) was applied at a rate of 0.04 lb/yd². Zinc sulfate (water soluble) was applied at a rate of 0.01 lb/yd². After application of the tracer, the dust control products were applied according to the manufacturer's recommendations. Test plot data are given in Table 1.

Particulates being removed from the plot by wind movement were sampled with saltation catchers, 36 in. plastic tubes with a 2 in. wide vertical slot sampling the 12 to 30 in. height interval. Four catchers were placed at each plot, oriented at the midpoint

Table 1
Exposed Area Test Plots

Test Plot	Plot Size	Tracer	Pre-emergent	Dust Suppressant Tested		
				Name	Application Concentration	Application Rate
1	50 ft. X 50 ft.	zinc sulfate	no	Soil Seal	0.03%	1.0 gal/yd²
2	50 ft. X 50 ft.	zinc sulfate	no	AMSCO-RES 4281	20%	0.6 gal/yd²
3	50 ft. X 50 ft.	zinc sulfate	no	Fiber mat	8 oz./yd²	3 12-foot rolls
4	50 ft. X 50 ft.	zinc sulfate	no	Flambinder	17%	0.5 gal/yd²
5	50 ft. X 50 ft.	zinc sulfate	no	Genaqua	10%	0.2 gal/yd²
6	50 ft. X 50 ft.	zinc sulfate	no	Curasol	3%	0.3 gal/yd²
7	50 ft. X 50 ft.	zinc sulfate	no	M166 & M167	6%	0.5 gal/yd²
8	50 ft. X 50 ft.	zinc sulfate	no	Coherex CRF	25%	0.5 gal/yd²
9	50 ft. X 50 ft.	zinc oxide	no	Sherman Process (mulch, no grass seed)	--	--
10	50 ft. X 50 ft.	zinc oxide	no	Sherman Process (mulch, with grass seed)	--	--

Table 2
Saltation Sampler Results (ppm)

Test Plot	Date Established	Sample Date									
		6-11	6-25	7-3	7-13	7-20	7-25	7-30	8-8	8-22	8-31
1	5-24-84	78	97	--	111	85	311	155	101	183	170
2	5/11/84	71	114	44	121	121	170	322	111	172	204
3	5/18/84	42	163	74	125	65	<30	<65	28	252	120
4	5/25/84	69	105	35	116	55	--	166	219	140	119
5	5/18/84	91	172	176	152	90	65	58	128	141	217
6	5/24/84	75	111	42	130	67	58	97	97	167	128
7	5/24/84	64	76	42	96	67	151	152	156	160	122
8	5/24/84	113	162	36	100	72	454	118	174	206	214
9	7/10/84									513	132
10	7/10/84									157	103

of each side with the sampling slot facing the plot. Samples from the saltation catchers were taken roughly once each week during the test period and were analyzed for zinc by atomic absorption spectroscopy. The results of the saltation sample analyses are shown in Table 2. Values over 75 ppm (the background concentration of zinc in the soil tested in each plot) indicate failure of the dust suppressant.

The data indicate integrity of the crust on all plots on June 11 except Plots 5 and 8. Time since application varied from 17 to 31 days. Two weeks later, on June 25, only Plot 7 remained near the background level of zinc in the soil. Values remained above background levels on most plots throughout the period. A notable exception was the fiber mat where values decreased below background by July 20 and remained there for a month.

A problem with all plots was the rapid regrowth of vegetation. All plots had been stripped of vegetation before application of the tracer and dust suppressant. The rationale for this action was that a dust suppressant spray could not form a dirt crust in the presence of vegetation stems, because the dust suppressant would not uniformly pass the vegetation and reach the soil. When vegetation did grow, it penetrated the crust, and a small dirt pile was seen around each stem. Testing of these dust piles indicated large quantities of the tracer material (>200 ppm). Applying this finding to hazardous waste sites, it is apparent that vegetation must be controlled if the crust is to stay intact.

The alternate approach of promoting vegetation as a dust control measure is discussed in the interpretation of findings section.

Control of Wind Erosion Dust Emissions from Storage Piles

The field study effort was designed to demonstrate the effectiveness of a windscreen, alone or in combination with other control measures, in reducing dust emissions due to wind erosion from an inactive waste storage pile. Concurrent upwind/downwind aerosol/windspeed measurements were made with real-time data retrieval around a storage pile protected by a windscreen.

The waste storage pile tested was not contaminated. The assumption was made that the hazardous material would be integrally bound to the soil and would therefore be emitted at a rate directly proportional to the loss rate of soil from the pile. The soil material in the pile was relatively erodible so that detectable concentrations could be obtained during short-term tests even with moderate (10 to 15 miles/hr) windspeeds. The soil selected was a very fine shredded topsoil. The size of the pile was established by determining a size large enough to accurately simulate wind erosion action from a temporary waste storage pile, yet not so large that it consumed a major portion of the study's resources. This "reasonable" size was estimated at about 8 ft high with an elliptical base 25 ft by 20 ft, or about 100 tons of shredded topsoil.

All atmospheric particulate concentrations were measured with RAM-1 continuous aerosol monitors. These instruments emit a pulsed light across a continuous flowing sample airstream and sense the amount of light scattering with a silicon detector. Running side by side, the five RAM-1s employed in this study had a sampling precision of about 5 μg/m³ when measuring ambient levels. The Ram-1s are stated to have an upper particle size range of 20-μm diameter, but are generally considered to have a 50% collection efficiency upper cut point of about 10 μm.

Windspeed and direction were measured with a Met One system that included six windspeed sensors and one direction vane. The anemometer sensors had an accuracy of ±5 degrees.

Both the RAM-1s and wind instruments were connected through a translator and an analog-to-digital convertor to an Apple IIe computer onsite that collected the individual signals during testing, displayed the readings continuously, averaged

INTERPRETATION OF FINDINGS

Control of Wind Erosion Dust Emissions from Exposed Areas

The dust suppressants applied cost between $62 and $4840/acre in material cost, with a median cost of less than $800/acre. Based on tracer studies, 100% effectiveness varied from less than 17 days to 30 days. No re-applications were tested. However, it is reasonable to assume that control after re-application would be slightly greater than with the initial application.

The problem of weed control must be considered. Weeds punctured the crust formed by the dust suppressant. Around each stem was a small dirt pile which was highly contaminated with tracer. Spraying preemergent weed control on the plot before application of the dust suppressant largely solved this problem.

An alternate procedure to eliminating vegetative growth would be to encourage it. Products are available that are temporary soil binders impregnated with grass seed. While grass was beginning to grow, the same weed problem just described would occur. Assuming a thick stand of grass did grow, control would probably not be 100% since there would always be some loose dirt between grass stems. Chemical dust suppressants sprayed on thick grass stands would not be effective because the suppressant would stick to the stems and little would penetrate to the soil.

Control of Wind Erosion Dust Emissions from Storage Piles

Test results show that the windscreen showed no consistent positive control effectiveness for particles in the <10 µm respirable range. Control effectiveness for particles >10 µm may be greater, but the study instrumentation could not measure this size range. Particles in the size range of 10-30 um can stay suspended for distances of several miles. Particles >30 µm usually fall back to the ground within a few hundred feet of the source.

Application of chemical dust suppressants to the pile were shown to be about 50% effective within three days of suppressant application. This effectiveness would decline with time, but the decay function was not established. Adding a windscreen upwind of a pile treated with a dust suppressant showed no incremental increase in control efficiency.

If a windscreen is erected to control the 10-30 µm size fraction (control efficiency unknown), the screen should be higher by 2 to 4 ft than the top of the pile, or negative control efficiencies may result at certain downwind distances.

The combination of a windscreen and chemical dust suppressant was unable to achieve 100% control. Therefore, some downwind exposure to contaminated dirt from storage piles can be anticipated.

Control of Dust Emissions from Active Site Cleanup

Water spraying over the area being worked by a front-end loader and truck at the rate of 0.9 gal/yd^2 resulted in a control efficiency of about 50% for the front-end loader working area and about 65% for the material dump area. Adding surfactant to the water allowed the use of less water (0.75 gal/yd^2), while increasing control efficiency to about 70% for both the FEL working area and FEL dumping area. Dryer conditions than those experienced at the test plot would require more water. It is unlikely that any acceptable level of area watering would significantly increase control levels measured. Therefore, the goal of 100% control efficiency does not appear possible with this technology, potentially causing subsequent human exposure impacts.

DISCLAIMER

Although the research described in this article has been funded in part by the USEPA through contract No. 68-02-3512, it has not been subjected to the Agency's required peer and administrative review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

them over 1 min, 5 min, and 1 hr time periods, and stored the averages for later retrieval. All the calibration values could be changed by inputting new values to the computer.

Both the upwind sampling stand and the main downwind stand had RAM-1s and windspeed sensors mounted at 3.3 ft and at 6.6 ft heights. The upwind stand also had the wind direction vane mounted at a height of 6.6 ft. The third sampling stand, which was alternated between a location beside the main downwind stand and a further distance downwind, had a RAM-1 and windspeed sensor only at a height of 3.3 ft. A sixth windspeed sensor was located at the upwind edge of the pile at a height of 3.3 ft.

Results from the tests showed that the windscreen did not consistently attain a significant level of control of particles $\leq 10 \mu m$ (the inhalable size fraction measured by the RAM-1). The screen was effective in reducing windspeeds, but this did not result in commensurate reductions in $\leq 10 \mu m$ concentrations from the pile. A possible explanation for this phenomena is that the wind erosion emission rate of particles $\leq 10 \mu m$ is fairly constant at windspeeds above a threshold of about a 7 miles/hr hourly average. Additional soil losses associated with higher windspeeds are particles $>10 \mu m$ not detectable by the RAM-1.

In tests of the pile with a chemical dust suppressant applied within three days of testing, control effectiveness in the range of 50% was measured. Adding the windscreen to a pile previously treated with the dust suppressant showed no incremental increase in control effectiveness.

In tests with different pile to windscreen distances, it was found that a distance of two screen heights was superior to a distance of five to eight screen heights. In fact, with the same pile height as screen height, concentrations at 50-80 ft from the pile were higher at a 6.6 ft height with the screen than without the screen. This is caused by wind shear from the screen.

Control of Dust Emissions from Active Site Cleanup

The operation selected for testing consisted of a front-end loader (FEL) and dump truck combination. The FEL scraped material from the surface, turned, traveled to the dump truck, and dumped its load into the truck. This activity simulated the most common method of loading contaminated soil into trucks for off-site disposal.

Rather than adapting a test array to the requirements of an existing cleanup site operation, it was decided to use captive equipment at a non-hazardous site. The equipment activity could be directed by the field team to fit the needs of the testing without interfering with a production schedule and without other dust sources interfering with the testing. The use of a noncontaminated site for testing required the assumption that the toxic material would be uniformly dispersed in the soil, and that toxic soil particles and non-toxic soil particles behave the same in the air.

The exposure profiling method was used to sample the dust emissions downwind of the operation. This method employs a tower with multiple profiling heads to perform simultaneous multipoint isokinetic sampling over the plume cross-section. This technique is applicable to point and line sources where a ground-based profiling tower can be located across the plume cross-section and where the distance from the source to the samplers can remain fixed. The primary sampling instruments were profiling heads utilizing the stacked filter concept. The sampling head internally fractionates the dust sample by particle size. Multiple heads were mounted on each tower to sample at several points in the plume directly downwind of the operation. Three profiling towers were used. One tower was located upwind of the operation to measure the background concentration not attributable to source operation. A similar sampling tower was located downwind of the FEL scraping and traveling path to test the scraping emissions. The other tower was equipped with a horizontal cross arm and was located downwind of the dump truck to test the dump cycle emissions.

Four control measures were tested. Only two are reported in this paper due to data availability. On each sampling day, both an uncontrolled and controlled test were made. The control effi-

ciency is merely the difference in emission rate per unit activity between the uncontrolled and controlled tests.

Control Measure 1 consisted of spraying the active working area of the FEL and dump truck with water. In the few instances where dust control measures are currently in use at hazardous waste sites, this is the control being used. Using a portable 200 gal tank, pump, generator, hose and nozzle, the working area was sprayed prior to the controlled test and again during the test as the field team noted drying of the surface and visible emissions. Watering amounts averaged 0.9 gal/yd². More water was used on the travel paths of the FEL and dump truck than on the scraping area. These active travel areas dried much faster than the scraping area. It was noted throughout the testing that only the top 1 to 2 in. of the surface were dry. Below this dry crust, the soil was very damp.

For Control Measure 2, application procedures were identical to those used in plain water application. However, a surfactant, Johnson-Marsh Compound MR, was added to the water to form a 1:1000 dilution of surfactant to water. Somewhat less watering was needed for these controlled tests. The surface remained damp longer, and fewer subsequent applications were required. Application of the water/surfactant mixture averaged about 0.75 gal/yd².

Results are shown in Table 3. Emission rates for FEL travel and scraping are in units of lb/vehicle mile traveled. Emission rates for the FEL dump are in units of g/yd³. Emissions rates can be used to approximate off-site exposure with assumptions about particle deposition. Water controlled FEL travel/scraping emissions by 42% and 64%, respectively, for < 30-μm and < 2.5-μm (TSP and FP) size particles. Surprisingly, the emissions from the material dump were reduced 63 and 70% for TSP and FP micrometer size particles. Adding surfactant to the water increased control efficiencies slightly, while allowing the quantity of water used to be reduced. TSP control efficiency for the FEL travel/scraping increased from 42% to 69% with the addition of the surfactant. Other control values were similar.

Table 3
Control Efficiency of Area Spraying for Controlling Emissions from Soil Loading by FEL into a Track

Control and Index	Emission Rates[a]				Control Efficiency, %	
	No Control		Control			
	≤ 2.5 μm	≤ 30 μm	≤ 2.5 μm	≤ 30 μm	≤ 2.5 μm	≤ 30 μm
Front-end Loader Travel/Scraping						
Water (5 tests)						
Max. Value	0.96	1.51	0.28	0.86	90	56
Min. Value	0.09	0.41	0.03	0.30	30	27
Mean Value	0.48	1.11	0.15	0.62	64	42
Surfactant (4 tests)						
Max. Value	0.79	2.69	0.29	0.66	95	75
Min. Value	0.20	1.16	0.01	0.45	45	61
Mean Value	0.48	2.01	0.17	0.59	66	69
Front-end Loader Material Dump						
Water (5 tests)						
Max. Value	1.18	3.24	0.33	1.42	95	88
Min. Value	0.05	0.26	0.03	0.15	40	31
Mean Value	0.74	2.18	0.10	0.65	70	63
Surfactant (4 tests)						
Max. Value	0.85	8.98	0.43	2.93	82	88
Min. Value	0.17	4.36	0.07	0.94	46	56
Mean Value	0.59	6.88	0.22	1.51	62	77

[a] Emission rates for FEL travel/scraping are in units of lbs/vehicle mile traveled. For the FEL material dump, emissions are in units of grams/yd³.

SAFETY PLANS FOR UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

The development and implementation of effective, workable safety plans for investigation and remediation projects at uncontrolled hazardous waste sites can be challenging tasks for even the most experienced health and safety professional. These operations can present an alarming array of potential chemical and physical hazards that must be recognized and controlled for worker protection. Ranging from the multiple inherent hazards of the chemicals to physical hazards from earth moving, excavation, trenching, demolition and heat stress, the potential risks to workers demand a comprehensive detailed site safety plan. Key elements considered essential for meeting this challenge are presented as a basic framework for developing such a safety plan.

Safety Plan Components

Each site safety plan should include, as a minimum, the following categories of information presented in sufficient detail to adequately address specific site hazards:
- Introduction, purpose and scope
- Key personnel and assignment of safety responsibility
- Job hazard analyses
- Air Monitoring requirements
- Medical surveillance program
- Employee training and information
- General safe work practices
- Personal protective equipment
- Work zone delineation and decontamination procedures
- Emergency response plans
- Site security measures
- Recordkeeping requirements

The contents of each plan section will vary depending upon the scope of the site operations, and individual safety plans may require additional sections. For example, maintaining an up-to-date version of a plan once it has been approved and implemented is extremely important. Some planners may wish to include a section that specifically describes the mechanism for amending the preliminary safety plan. The author's intent is to provide a general outline, to list important considerations for each section and to provide sufficient information for development of a workable, comprehensive safety plan.

INTRODUCTION, PURPOSE AND SCOPE

The introductory paragraphs of the safety plan should describe the nature of the work planned; potential chemical, physical and biological hazards likely to be encountered; the overall intent of the plan; and the scope of authority with regard to contractors, subcontractors, site visitors and regulatory agency personnel.

Written safety procedures for site operations must be based on the best available information. For preparing the preliminary site safety plan, historical information describing past cleanup operations, previous waste streams, off-site releases, news media coverage, recorded health or safety violations, etc., can be very useful tools for the industrial hygienist or safety professional. Useful sources of historical information might include:
- Site records such as waste receipts, storage inventories, manifests or shipping papers
- Waste generator records from firms that contributed waste to the site
- Regulatory agency records such as those from local or regional air and water pollution control boards, OSHA, fire departments, health departments and federal or state investigative teams
- Previous site workers, management personnel and residents near the site who may have personal knowledge of site operations[1]

When actual operations begin, the preliminary safety plan must be amended, enhanced or rewritten to provide operational safety procedures. An initial site survey should be conducted prior to this stage to determine the actual extent of chemical, biological, radiological and physical hazards likely to be encountered by site workers. The site survey should include both a walk-through survey of the work areas and initial monitoring and sampling of site materials. Information from the site survey should be readily available to site workers and may even be included as an integral part of the safety plan. More commonly, however, this information is provided in crew briefings, agency meetings and site log books.

KEY PERSONNEL AND ASSIGNMENT OF SAFETY RESPONSIBILITY

The plan should include a complete listing of key supervisory, management and safety personnel and a description of their responsibilities for implementation of the plan. Clear lines of authority must be established for enforcing compliance with the safety procedures. Responsibility must be assigned for determining the existence of unsafe conditions, and proper authority must be granted to stop unsafe operations.

JOB HAZARD ANALYSIS

The job hazard analysis is used to identify those job categories with the greatest hazard potential and to aid in specifying the per-

sonal protective equipment selection procedure. The analyses should describe each job function, provide a qualitative estimate of the employee exposure potential for each job function and describe the expected production rates and worker efficiency for each operation.[2]

The analyses should also include a complete listing of expected chemical hazards with permissible exposure limits or recommended threshold limit values. Recommendations for specific personal protective equipment and protective measures should be included in this section of the plan.

In addition to the chemical hazards, consideration should be given to physical hazards such as being struck by, struck against or being caught in, on or between site materials, structures or machinery. The analysis should include such items as: slipping, tripping and falling hazards, work at elevated locations, heat stress, excessive noise, confined space work and electrical hazards, to name a few.

AIR MONITORING REQUIREMENTS

Specific air monitoring procedures, including collection methods, sampling strategies, recordkeeping and action levels for implementing contingency plans, both on and off the site, should be developed for each site safety plan. The detail required for this section of the plan is dependent in most cases on the nature of the site contaminants, wind and weather conditions, the proximity of the site in relation to homes and businesses and the specific regulatory agency requirements. There are, however, basic components of an air monitoring program that deserve consideration in any plan. Buecker[3] lists the following objectives for site air monitoring:
• Monitor for excursions above on-site and perimeter action levels for the purpose of mitigating emissions or initiating evacuation
• Substantiate the selection and use of appropriate levels of respiratory protection and protective clothing
• Provide a continuous historical record of personal exposures and site emissions, including baseline emissions
• Establish a sample characterization mechanism to be used for the screening of samples or for a contingency such as a chemical exposure incident.

MEDICAL SURVEILLANCE

Initial medical surveillance for hazardous waste site workers should include:
• Thorough review of the employee's medical, personal, family and occupational histories
• Thorough physical examination and clinical evaluation
• Laboratory evaluation for selected biological samples such as blood chemistry, heavy metals screen, cholinesterase levels, etc., at frequencies determined by the physician[4]

The safety plan should provide sufficient information to site management and medical personnel to make valid decisions about medical acceptability of assigned workers. In most cases, the medical surveillance program should be administered by a qualified site industrial hygienist or safety professional.

Ongoing medical surveillance and biological sampling criteria should be provided by an occupational or industrial physician. Information on specific medical examination requirements should be listed in the safety plan.

EMPLOYEE TRAINING AND INFORMATION

Before an employee can be expected to work safely, he or she must be properly trained. The safety plan should at least describe the minimum acceptable level of safety training required for assignment to a hazardous waste site. The purpose of the basic safety training is, of course, to make employees aware of the safety and health hazards they will encounter, the procedures and equipment required to protect themselves and their role during emergency conditions. The extent of required training will depend greatly on the specific job assignment and information gathered from the job hazard analyses.

Certain hazardous operations will require additional training beyond the traditional employee orientation, hazards awareness and respirator training. Some specific examples of operations that require additional employee training include: confined space entry, explosives handling, welding and cutting operations, emergency first aid and CPR and fire fighting.

Employee information sources should also be addressed in the site safety plan. This might include a description of the location of material safety data sheets, air sampling results, appropriate health and safety posters, technical reference texts and names of personnel with specific site safety information.

GENERAL SAFE WORK PRACTICES

This section should describe the general measures workers must take to prevent exposure to hazards. Examples of these measures would include:
• Exclusion of food, beverages and tobacco products from the contaminated work areas
• Personal hygiene requirements include the need for showering at the end of the work shift, washing the hands and face before eating, drinking or smoking
• Labeling requirements for containers of debris, waste, cleaning materials, etc.
• Segregation procedures for reactive and incompatible waste materials
• Precautions which may require additional, more specific safety procedures for operations such as excavation and trenching, confined space work, hot work, explosives handling, etc.

One particular safety concern that should be addressed as part of the general safe work practices is the need for heat stress control measures. Hazardous waste site cleanup operations are often scheduled during the dry summer months to avoid rainwater and groundwater accumulation problems. Workers, equipped with impermeable vapor barrier clothing and respirators, are at greater risk from heat stress and the associated heat illnesses.[3]

Several different heat stress indices have been developed through the years as researchers sought to find an index which is physiologically valid over a wide range of hot environments. More than a dozen heat stress indices are described in the research literature.[4] The most commonly referenced index, the Wet Bulb Globe Temperature (WBGT), has been widely accepted and is often used to develop work/rest schedules for hazardous waste site operations to control heat stress.

The safety plan might also include some of the USEPA heat stress monitoring criteria' such as: measurement of before and after work body weight to ensure adequate body fluid replacement; monitoring of the heart rate during rest periods to ensure proper recovery from heat stress; and monitoring of oral temperatures (as an indicator of core temperature), also to ensure proper recovery during rest periods.

Consideration should also be given to the recommendations for adequate heat acclimatization described in the NIOSH criteria document for heat stress control.[3]

PERSONAL PROTECTIVE EQUIPMENT

This section of the safety plan must describe specific respiratory protective devices and protective apparel required for each job classification and/or specific operation on-site. The established USEPA protection levels for personal protective equipment,' coupled with an ongoing assessment of both respiratory and skin hazards, can serve as a basis for developing site specific protection levels for the safety plan.

The USEPA protection levels describe personal protective equipment requirements in four categories according to the degree of protection afforded. These are:
• Level A should be worn when the highest level of respiratory, skin and eye protection is needed. Equipment would include an SCBA, a fully encapsulating environmental suit and appropriate head, hand and foot protection.

•Level B should be worn when the highest level of respiratory protection is needed, but a lesser level of skin protection can be safely used. Equipment would include an SCBA, appropriate chemical-resistant clothing (selection based on types of exposures, chemical resistance, suit construction, permeation protection, etc.) and appropriate head, hand and foot protection.
•Level C should be used where minimal respiratory and skin hazards are present and should be selected only when the specific types of respiratory hazards are known, the concentrations have been measured and the criteria for selecting air purifying respirators are met. Equipment would include a full face chemical cartridge or cannister type air purifying respirator, appropriate chemical resistant clothing and appropriate head, hand and foot protection.
•Level D is the basic work uniform and should be worn only when no respiratory or skin hazards are encountered.

The OSHA respiratory protection standard (29 *CFR* 1910.134)[9] requires that employee exposures to harmful airborne chemical contaminants shall be controlled, whenever feasible, by accepted engineering and administrative control measures rather than rely solely on the use of respirators for routine operations. Examples of accepted control measures would include the use of general and local ventilation, enclosure or isolation of the chemical process or operation and substitution of less toxic materials.

Hazardous waste site operations, however, are not amenable to the use of traditional control measures. They frequently require materials handling activities with high potential for chemical exposure and necessitate the use of elaborate levels of protective equipment. The selection, use and maintenance of personal protective equipment must comply in all respects to the requirements of the OSHA standards. Careful consideration should also be given to recommendations provided by the recognized consensus standards for respiratory protection such as those from the American Industrial Hygiene Association,[10] the American National Standards Institute[11] and the National Institute for Occupational Safety and Health.[12]

Specific criteria for selecting protective clothing have not yet been developed. The American Conference of Governmental Industrial Hygienists (ACGIH) has published, however, a very useful field guide and technical reference manual, *Guidelines for the Selection of Chemical Protective Clothing*,[13] which should aid in the development of protection levels for the safety plan. Additional information is available from technical publications such as the *American Industrial Hygiene Association Journal*, NIOSH publications and the *Journal of the American Society of Safety Engineers*.

WORK ZONE DELINEATION AND DECONTAMINATION PROCEDURES

Delineation of site work zones, based on the types, locations and exposure potential of chemical substances, is an effective means of preventing or reducing the possibility of exposure and translocation of substances. Heavily contaminated areas are delineated with physical barriers, control points are established and decontamination facilities and procedures are established to prevent spread of contamination. The USEPA recommends the use of three contiguous work zones:
•*The Exclusion Zone*, the area of highest contamination or with the greatest potential for exposure, separated from the next zone by the "Hotline" or step-off point (appropriate protective equipment must be donned before crossing the hotline)
•*The Contamination Reduction Zone*, which provides a transition area between the contaminated and clean areas and contains the necessary decontamination equipment, washing areas and decontamination solutions
•*The Clean or Support Zone*, the outermost area which is uncontaminated and contains the command center and support equipment

The USEPA control system is based on a "worst case" situation. Less stringent control measures can be used if timely, accurate information from air monitoring, safety inspections and substance and soils sampling is available.

Decontamination procedures must be developed and included in the safety plan. Employees must be properly trained, and decontamination solutions must be properly handled and disposed. The extent of decontamination required will depend on a number of factors, the most important being the types of contaminants involved. Other factors may include: the amount of contamination on protective clothing that can be visually detected; the types of personal protective equipment utilized; the specific work function (and hazard potential) of each individual; and the reason for leaving the controlled area, either for routine or emergency exit.

EMERGENCY RESPONSE PLAN

Emergency response (or contingency) plans can take many forms from simple telephone rosters, action guides and checklists to comprehensive, detailed procedures. Contingency plans for hazardous waste site operations, particularly in the remedial action phase, should be as comprehensive and detailed as possible. Consideration must be given to existing community contingency plans which will interface with site activities. Local agencies for spill response, ambulance, fire, police and regulatory control must review and approve the plan. Interfacing, coordinating and using existing contingency plans should be major goals of the site emergency response plan.

Plans for emergency response should address, as a minimum, the steps to be taken for:
•Hazardous chemical reactions, fires and explosions
•Site evacuation and emergency assembly areas off-site
•Community notification, evacuation and emergency medical treatment
•First aid and CPR and locations of emergency and fire fighting equipment
•Emergency response assistance, including ambulance, fire, hospital, police and poison control centers[14]

SITE SECURITY

Uncontrolled hazardous waste sites are typically newsworthy, and cleanup operations can easily become a local attraction for area residents. Control of access to unauthorized visitors is essential. The security section of the safety plan should include: the specific measures for identifying authorized personnel, such as the use of photo identification badges; a requirement for maintaining logs of visitor names and vehicle license numbers; the names and specific duties of security personnel; and the specific procedures for controlling site access (road closures, check points, barriers, fences, etc.). Any measures taken should be approved and coordinated with local emergency service agencies such as fire, police and ambulance personnel who may respond to site emergencies.

RECORDKEEPING REQUIREMENTS

The safety plan must be well documented throughout site operations. In all cases, the records maintained must conform to established agency policies and procedures and applicable OSHA regulations. The safety plan should describe specific documentation requirements. Typical site documents might include:
•Employee training records including proof of respirator fit tests
•Safety equipment inspection and maintenance records
•Health and safety meeting reports
•OSHA logs of injuries and illnesses
•Accident investigation reports
•Personnel exposure monitoring records
•Emergency incident reports
•Contingency plan meeting reports
•Applicable safety regulations and guidelines

CONCLUSIONS

Uncontrolled hazardous waste sites pose a serious risk to workers involved in investigation and remediation operations. Multiple hazards from chemicals, structures, machinery and cleaning operations must be controlled for worker protection. Written, understandable safety procedures, based on the best available site information, must be provided to all personnel.

The information provided in this paper is intended to serve as a basic outline for the development of effective safety plans. In any situation, the extent and application of the plan sections presented should reflect the special considerations of each specific site.

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HEAT STRESS MONITORING AT UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

It was not the intent of the authors of this paper to discuss USEPA policy or policy development. Rather, the authors wish to share their experiences in trying to deal with hot workplace environments at hazardous waste sites and monitoring employees for heat stress. While the USEPA, Office of Emergency and Remedial Response, Hazardous Response Support Division, *Interim Standard Operating Safety Guides* is not USEPA policy, it is used by many USEPA personnel as a basic reference in addressing such site specific problems.

1982 INTERIM STANDARD OPERATING SAFETY GUIDES

The *Interim Standard Operating Safety Guides,* published in Sept. 1982, while not USEPA policy, suggests that there be four primary classifications for protective clothing and respirator protection:
- Level A—Encapsulating suit with SCBA
- Level B—Hooded Chemical splash suit with SCBA
- Level C—Hooded skin protection with air purifier canister respirator
- Level D—No respirator protection and minimum skin protectors

Since the *Guides* discourage the use of Level D, site activities are conducted in Level A, B or C, thus presenting a potential for heat stress during warmer periods. In addition, Regions II, IV, VI and IX find themselves with the additional problem of working in areas where temperatures and humidity are higher than generally found within other Regions in the continental United States.

The *Guides* suggest a heat stress monitoring program be implemented when employees are wearing impervious clothing and ambient temperatures are 70 °F or above. The frequency of monitoring should increase as temperatures increase and employees should be monitored after every work period once temperatures exceed 85 °F.[1] The *Guides* suggest the following monitoring program:
- Heart rate (HR) should be measured by the radial pulse for 30 sec as early as possible in the resting period. The HR at the beginning of the rest period should not exceed 110 beats/min. If the HR is higher, the next work period should be shortened by 10 min (or 33%), while the length of the rest period stays the same. If the pulse rate is 100 beats/min at the beginning of the next rest period, the following work cycle should be shortened by another 33%.
- Body temperature should be measured orally with a clinical thermometer as early as possible in the resting period. Oral temperature (OT) at the beginning of the rest period should not exceed 99 °F. If it does, the next work period should be shortened

by 10 min (or 33%), while the length of the rest period stays the same. And, if the OT exceeds 99.7 °F at the beginning of the next period, the following work cycle should be further shortened by 33%. OT should be measured again at the end of the rest period to make sure that it has dropped below 99 °F.
- Body water loss (BWL) due to sweating should be measured by weighing the worker in the morning and in the evening. The clothing worn should be similar at both weighings; preferably, the worker should be nude. The scale should be accurate to plus or minus 0.25 lb. BWL should not exceed 1.5% of the total body weight. If it does, the worker should be instructed to increase his daily intake of fluids by the weight lost. Ideally, body fluids should be maintained at a constant level during the work day. This requires replacement of salt lost in sweat as well.
- Good hygienic standards must be maintained by frequent change of clothing and daily showering. Clothing should be permitted to dry during rest periods. Persons who notice skin problems should immediately consult medical personnel.

While these guidelines are extremely helpful, it is not always possible to implement them at every hazardous waste site. For example, the Environmental Response Team (ERT), as well as various USEPA Regional personnel, have found it extremely difficult to obtain body weights on-site. ERT has found it helpful to substitute taking the employee's blood pressure for body weight. While this is not a direct measurement for heat stress monitoring, it does alert on-site safety and health professionals of those employees who should be watched closely because of high blood pressure as well as indicate an individual's overall stress as the response develops.

CASE HISTORIES
Dioxin Site, New Jersey

Site activities occurred during a typical hot, humid New Jersey summer day. What makes operating procedure here noteworthy is some of the heat stress equipment utilized during this activity. The site was located within an industrial park in central New Jersey. It consisted of several large concrete slabs which were once the floors for warehouses, etc., broken asphalt parking lots, storm drains, sand/clay/gravel spots as well as some vegetation areas.

All site personnel were wearing Level C (Hooded Tyvek/Saran disposable suits, full face air purifying respirator with industrial size pesticide canisters, gloves, etc.). The on-site tasks consisted of two major efforts: collecting and blending soil samples.

The blending operation required the use of 110 A/C power and was located near the decontamination area. Since shade trees were absent, inexpensive beach umbrellas were purchased and placed within the area to extend the work periods from the scheduled 20 min. Blender personnel were in the same Level C protection as the samplers: however, they did not have communication radios.

The soil samplers were in Level C protective equipment and worked for 20 min followed by a 20 min rest period. The sample grid had been laid out in advance to reduce the amount of time on-site. The decontamination line was modified slightly from those set forth in the *Interim Standard Operating Safety Guides* by adding an annex. The annex, designated as a rest area, was located just past the gross decon area in the decon line. This area was shady and stools were provided.

In attempting to implement heat stress monitoring as described in the *Guides*, the following were some of the major problems encountered:

•The accuracy of the scale was inconsistent.
•Blood pressures were hard to hear and a limited number of people were qualified to take them.
•The decon line was slowed due to the timely process of taking temperatures.
•It was difficult for the site Health and Safety Officer to take pulses at the appropriate time.

The following is a summary of how the problems were addressed and resolved:

•Since the duration of the on-site sampling project was less than 6 days, the body weight requirement was deleted from the on-site monitoring. Blood pressure measurements were taken at each rest period instead of the body weight.
•Initially, the blood pressure was obtained with the traditional stethescope and sphygmomanometer. However, this had two major drawbacks:
  1. The Safety and Health personnel had a difficult time hearing blood pressure because of background noises, i.e., diesel engines and employee conversations.
  2. In addition, it took approximately 3 to 8 min to monitor each person coming into the rest area. This type of monitoring became a "bottle neck" in personnel traffic flow. The problems were eliminated by incorporating the use of three digital electronic blood pressure monitors.
•Oral temperatures were originally collected using a traditional oral thermometer and this slowed personnel movement through the decon line. This problem was eliminated by the use of several digital thermometers for the sampling crew to use during their rest period.
•Pulse rates were taken at the wrist and/or throat. This was a time consuming and difficult task to conduct on personnel coming off the site. This problem was solved since the digital electronic blood pressure monitors also took pulse rates.

Pacific Islands

The project began in January 1983 when the Region IX, USEPA Emergency Response Section and the Technical Assistance Team (TAT) were asked to perform preliminary assessments on sites in Micronesia. The sites were located in Guam, an unincorporated territory of the United States, and several islands in the Trust Territories of the Pacific Islands (TTPI). The TTPI consists of the emerging political entities of the Commonwealth of the Northern Marianas Islands (CNMI), the Federated States of Micronesia (Kosrae, Ponape, Truk and Yap), the Republic of the Marshall Islands and the Republic of Palau. Guam, the center of business activity for the region, is located approximately 2700 km south of Tokyo and 500 km west of Honolulu.

Approximately 50% of the sites contained improperly stored and leaking transformers. Previous site surveys had identified many of the transformers as being PCB-contaminated. The remainder of the sites primarily contained pesticide and miscellaneous hospital laboratory wastes.

One of the prime concerns during the planning stages was the effect of the extreme temperatures and humidity. The Islands are located only 7 to 13 degrees above the Equator and temperatures range between 85° and 100°F even during the night. Humidity averaged from 80 to 100%. Since the team would be wearing protective gear, the heat stress potential was substantial.

In addition to heat-related illnesses, heat stress can increase the probability of accidents and result in a loss of efficiency. This was an important factor to consider since each team operated with only six people. Although an adequate amount of time was initially allocated for each island cleanup, operational delays coupled with the discovery of additional sites, required the team to work 18 hours a day.

The team completed 35 cleanups in 12 weeks. The majority of the work, which required protective gear, was carried out after sunset. This was the most important factor in reducing the heat stress potential. In addition, five other factors warranted attention.

Choice of Monitoring Guidelines

The existing USEPA and TAT Region IX heat stress policy calls for monitoring oral temperature, blood pressure and pulse rate in addition to weather conditions using an electronic thermometer and sphygmomanometer, an outdoor thermometer and a wind speed indicator. This policy was adopted in the Pacific cleanup.

Once in the Islands, a USCG Emergency Medical Technician monitored each person for conditions which could increase the probability of heat stress; however, it was occasionally necessary for workers to monitor themselves. Workers were more concerned with cooling down (drinking liquids, stripping protective clothing) than heat stress monitoring and this decreased the ability of the program to identify heat stressed workers.

Availability of Emergency Medical Care

Only basic emergency medical care was available on each Island and the team faced communication difficulties as each Island had its own native language. For these reasons, it was necessary to make provisions for the airlifting of injured personnel to Guam or Honolulu. Unfortunately, air service to the Islands is limited, averaging only two to three flights per week. In addition, suitable charter aircrafts were unavailable on the outer Islands. Therefore, the team made arrangements with the Department of Defense, which operates Civilian Assistance Teams (CAT Teams) on most of the Islands, to provide medical air evacuations if they were needed.

Availability of Potable Water

It was expected that potable water would be unavailable on most Islands since Micronesia was suffering a severe drought. The teams also anticipated that the water available would be contaminated with bacteria. This was compensated for by equipping both teams with halozone, a chlorine based disinfectant. Because this chemical leaves an unpleasant taste in the water, the team made fruit juices available. As it turned out, water was available almost everywhere but was usually contaminated. On some Islands, the team was able to obtain potable water from the CAT Team.

Acclimatization

Climate acclimatization was a major problem in the response effort. Because the team was used to the generally cool San Francisco climate, it required up to a week for all of the team members to acclimate to the Micronesian heat and humidity. Temperatures and humidity conditions also varied from island to island, sometimes significantly. This variation necessitated an additional acclimatization period of several days. Unfortunately, because interisland flights were infrequent, these periods were sometimes unavailable.

"Cool Down"

The team's concern with "cool down" was twofold. The probability of heat stress can be decreased by removing workers to a cool environment following work periods. When cleanups were in progress, the teams frequently worked 18-hr days so there was little time to recover from one day's work before another began.

Second, during mainland responses where heat stress problems are anticipated, firetrucks can be used to spray workers after their entries. This was not possible in the Islands, but ocean water and tropical rains adequately compensated for this. Air conditioning was the exception throughout Micronesia.

Generally, responses can be carried out safely in hot and humid remote areas of the world as long as the planning is adequate. From the USEPA's experience in the Islands and elsewhere in the region, the authors believe that blood pressure is clearly the most variable and least reliable indicator of heat stress. Oral temperature and heart rate are much better indicators. Both these parameters correlated with high temperature and humidity as well as with comments team members made about how they felt.

Triangle Chemical Site

This chemical company site near Orange, Texas, abandoned in 1981, was identified as a significant environmental and public health hazard. A planned removal action was carried out in August 1982. The ambient temperatures ranged from 86 °F to 100 °F with humidities between 80 and 100% during the entire operation.

The site safety plan included provisions for monitoring heat stress of employees. Pre-work pulse rates and blood pressure measurements were recorded during morning safety meetings. Readings were taken again after each on-site visit.

Workers were instructed on the importance of water balance to persons who perform tasks in hot environments wearing impermeable clothing while performing strenuous activities. They were advised to increase their daily intake of fluids to offset body water loss due to sweating and to increase the amount of salt used on food. Suitable replacement fluids were made available during working hours.

Body temperatures and weight loss were not measured at this location. None of the USEPA employees experienced problems while working. Only one individual was found to be affected by an elevated blood pressure level.

Cleve Reber Superfund Site

An emergency removal action was undertaken at the Cleve Reber, Sorrento Site in Southern Louisiana in the latter part of July 1983. The ambient temperatures registered 100 °F daily while the humidity was 100%. Immediate removal activities entailed removal of over 500 barrels.

The workers involved in this action were physically fit and acclimated to working in hot environments. Pulse rates were recorded at between 70-80 at rest. However, some individuals had an increase in heart rate of 180-190 beats per minute within 10 minutes after work began. Sensing thermometers were worn inside the workers' clothing; readings reached 125° while working in the sun and lowered to around 100 °F when in the shade.

The initial work schedule called for 60 min of work without stopping. The next hour consisted of 45 min work with a 15 min rest break. By 1:00 p.m., the schedule was 30 min work and 30 min rest. Eventually, the personnel were unable to work for more than 20 min at a time because of the intense heat and 20-340 min were required for recovery.

Portable showers were constructed using large fiberglass tanks for water storage, a shower head and a portable electrical generator. Workers moved to the established clear area, removed their Tyvek suits, gloves and tape, showered down in their clothing, sat down on a bench to rest, suited back up again with wet underclothing and returned for another work period. This procedure provided a rapid cooling down method.

Overall observations noted included:
•USEPA workers could not work as long as contractor personnel. The reasons included such factors as Saran vs. plan Tyvek suits, completely taped out workers around the glove and boot areas

vs. those that were not and full face respirators vs. 1/2 masks on contractor personnel.
•Oral temperatures were not always reliable. Some workers registered 103 °F temperatures with no apparent stress while others had readings of 97 °F with numerous effects.
•Half-mask respirators with faceshields and goggles were much easier and more comfortable to work in than full-face respirators.
•PVC or Tyvek/Saran suits are much more uncomfortable when working in hot environments than Tyvek suits. Plain Tyvek suits should not be worn unless chemical splash is not considered to be a problem.

Eastern Missouri

Since November of 1982, seven investigatory phases of the eastern Missouri dioxin investigations have been completed. The project involved the sampling of soil at more than 100 sites throughout eastern Missouri and the collection of nearly 5,000 soil and water samples for 2,3,7,8-TCDD analyses. The sampling procedures required the use of hand augers, picks, shovels and drill rigs.

The personnel protective equipment required while sampling for dioxin includes neoprene steel-toed work boots, full-body one-piece impervious protective suits, internal gloves of lightweight vinyl or latex, external viton gloves and a full-face respirator with combination organic vapor high-efficiency particulate cartridge/canisters. Wearing this type of personnel protective equipment poses a problem of possible heat stress as the ambient air temperature increases.

The work load of the personnel performing the sampling was probably moderate to heavy, and work at times involved lifting heavy objects such as augers, as well as strainful pick and shovel work. The work at other times was less vigorous, involving moderate walks or spooning soil into sample jars. When considering the type of work load involved, the permissible heat exposure TLV's are only valid when the worker is wearing light summer clothing. Since the clothing worn by the personnel was cumbersome and nearly impermeable, the work load was considered heavy.

The safety plan required that a heat stress monitoring program be performed as outdoor temperatures increased. The team leader calculated the WBGT at two hour intervals when the daily maximum temperature exceeded 60 °F. When the WBGT reached 82.2 °F or higher, medical surveillance of pulse and body temperature of team members were initiated.

The ambient outdoor temperatures were recorded upon arrival to the site and continually noted each hour until the on-site work was completed. Individual monitoring of those employees who were fully suited up (Tyveks, full-face respirators, viton gloves and steel-toed boots) also took place throughout the day. Personnel monitoring included weighing in and out each day, along with periodic checks of employees oral temperatures, pulse rates and blood pressures.

The equipment used for health monitoring included a bathroom scale for weighing the employees, a sphygmomanometer for measuring blood pressures and two IVAC monitors for determining employee's temperatures and pulse rates. A battery operated WBGT heat stress monitor was used for monitoring the outdoor temperatures.

Personnel monitoring began in the morning before leaving the Command Post. Each employee's weight was recorded along with his temperature, pulse rate and blood pressure. Upon arrival at the sampling site, the team set up its WBGT heat stress monitor and recorded the dry bulb, wet bulb, globe and wet bulb globe temperatures. As the employees began suiting up, their temperatures, pulse rates and blood pressures were measured. This personnel monitoring was repeated each time the employees unsuited for a break (approximately every one to two hours). After returning to the Command Post, the employees were again weighed to determine the amount of weight lost throughout the day.

No employee experienced heat cramps or heat exhaustion; however, there were a few times that workers definitely needed a break in order to unsuit and rest. Body temperatures often rose above 99 °F, with pulse rates of more than 100 beat/min. If an individual appeared to be extremely hot, he was given a wet cloth to wipe his arms and face, Gatorade or water to drink and was then seated in a shaded rest area. All workers recovered quickly and were able to continue working after a 15-30 min break.

CONCLUSIONS

As hazardous waste site occupational health and safety professionals know, heat stress monitoring is only one of the many difficult problems present during most operations. In addition to site conditions, one must consider other factors such as overweight workers, smokers vs. non-smokers, the food consumption of the employees during off-duty time and the wearing of dark plastic or rubberized items which are heated by the sun causing increased incidents of burns.

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DECISION MAKING FOR REMEDIAL ALTERNATIVES USING THE PROVISIONS OF CERCLA: PCB RIVER CLEANUP AND INDUSTRIAL SITE CLEANUP/CLOSURE

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INTRODUCTION

Erseco, Inc. has utilized the evaluation criteria of the National Contingency Plan (NCP) of CERCLA to provide guidance and construction of a decision making structure during remedial action planning for several hazardous waste sites. By using the NCP in conjunction with the provisions set forth in federal and state enforcement documents, Erseco was able to define the extent of remedy required at these sites and to evaluate, screen and select remedial alternatives which were the most cost effective and environmentally sound.

NATIONAL CONTINGENCY PLAN

On December 11, 1983, the Congress enacted CERCLA, which establishes broad federal authority to respond to releases or threats of releases of hazardous substances by undertaking short-term cleanup actions and/or long-term actions consistent with permanent remedy. Furthermore, the Congress directed the USEPA, under Section 105 of CERCLA, to amend the NCP to make federal responses to releases or threatened releases of hazardous materials "reasonably predictable by both the regulated community and the general public". On March 2, 1982, the USEPA proposed final rulemaking to amend the NCP which stated in the preamble that, based on USEPA's prior enforcement experience (pre-CERCLA), a flexible standard for determining the appropriate extent of remedy is the best standard at that time, and that a formal cost-benefit analysis for each remedial action alternative should be considered. On July 16, 1982, the USEPA published final rulemaking amending the NCP.

In essence, the USEPA structured the NCP provisions for determining the appropriate extent of remedial actions by opting for a flexible site-by-site approach rather than imposing rigid national standards; they chose to emphasize considerations of costs; they also chose to ensure that all remedies under CERCLA, whether publicly or privately financed, would be determined through basically the same cost/benefit approach.

The following case histories describe how the NCP provisions provided guidance and decision making structure during the remedial action planning for each site. The flexibility of the NCP criteria is evident through its adaptation to the particular circumstances concerning each case.

#1—GROUNDWATER CONTAMINATION

The first example case involves the discovery of organic chemical contamination in the groundwater of a municipal well field adjacent to a major chemical company. This discovery prompted the responsible chemical company to enter into agreements with the USEPA and the state to study the problem and begin cleanup. These agreements were in accordance with the federal government's jurisdiction under Section 7003 of RCRA and the appropriate provisions of state law. The settlement documents divided the site restoration work into two major phases: (1) Site Cleanup, and (2) Aquifer Restoration.

Site Description

The waste disposal sites at the chemical plant consisted of three major lagoon areas used for the disposal of process and cooling waters and an industrial landfill used for the disposal of solid wastes. Additionally, five "other waste sites" were used for the disposal of waste products.

The proximity of these sites to the municipal wells and surface waters is shown in Figure 1. A natural groundwater divide exists north of the manufacturing areas. To the south of the divide, groundwater flows in a southerly direction toward the river. To the north of the divide, the groundwater flows north toward a brook.

Contamination

Following the discovery of contamination at the municipal wells near the facility, an extensive groundwater monitoring network was installed at the site. Monitoring results indicated that several plumes existed within the aquifer system, and the chemical composition of the individual plumes was characteristic of the materials deposited at the various disposal locations (Fig. 2).

Several halogenated hydrocarbons were consistently present, the most common being VDC. Other halogenated compounds were also present. Volatile aromatics such as benzene, toluene and ethylbenzene were also found. The presence of these compounds was consistent with known waste disposal practices of the facility.

Remedy

According to the settlement documents agreed to by the USEPA, the state and the chemical company, the aquifer would have to be cleaned up and restored to a "fully usable condition."

The term "fully usable condition" was not defined in the agreements and, therefore, the required level of cleanup of the aquifer was not specified. Similarly, the agreements did not define the appropriate extent of remedy for the other waste sites. The screening criteria used to evaluate the alternatives to develop appropriate aquifer restoration and site cleanup plans consistent with these agreements was, therefore, complex and undefined. However, the National Contingency Plan (NCP) provided guidance for determining the appropriate extent of remedy with respect to government as
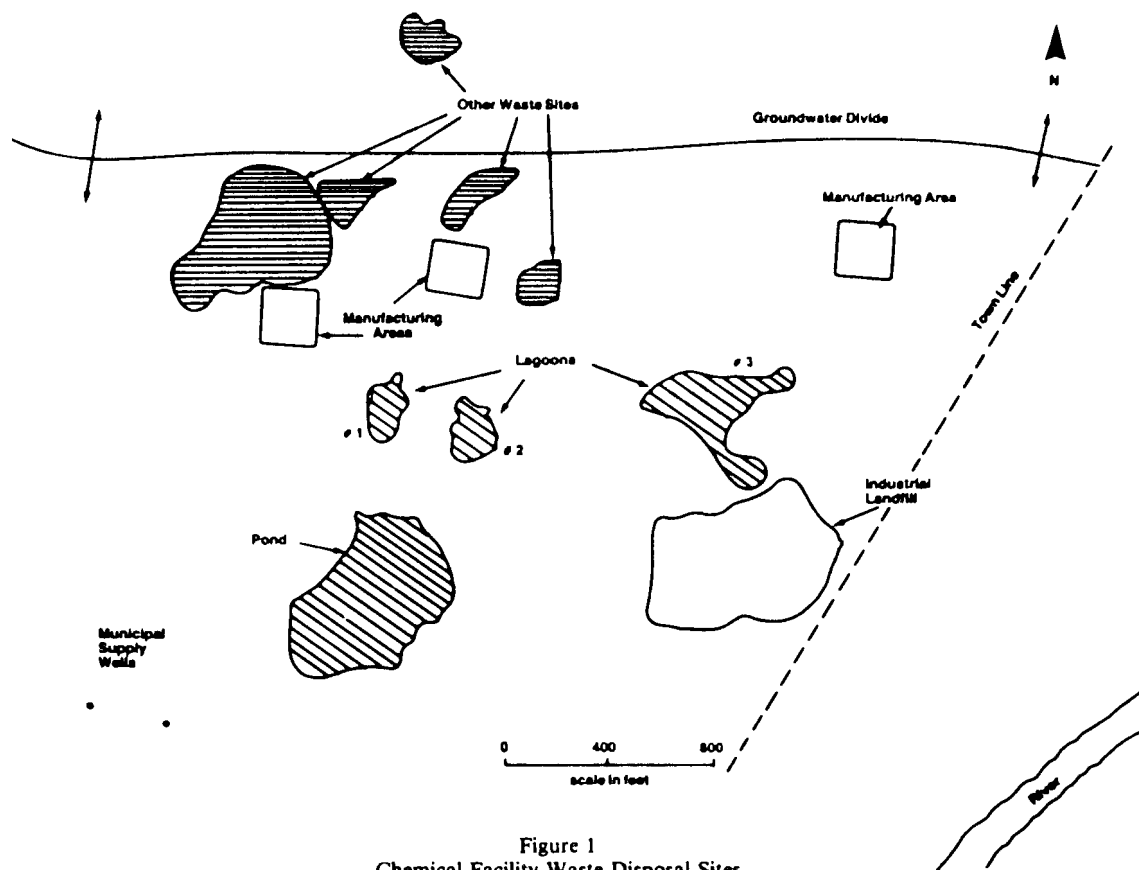
Figure 1
Chemical Facility Waste Disposal Sites

well as private-party financed cleanup activities. This is clearly stated under Section V of the March 12, 1982 Preamble to the NCP, *Enforcement Actions:*

"It is USEPA policy that the same factors used to determine the appropriate extent of remedy for fund-financed cleanup be considered to evaluate the adequacy of or determine the level of cleanup to be sought through enforcement efforts. Section 300.67(c) explicitly reflects this policy by providing that the criteria in section 300.67(e) through (j) will be used to determine the appropriate extent of remedy for private-party cleanup."

Paragraph (j) of Section 300.67 specifically refers to the extent of remedy as follows:

"The appropriate extent of remedy shall be determined by the lead agency's selection of the remedial alternative which the agency determines is cost effective (i.e., the lowest cost alternative that is technically feasible and reliable) and which effectively mitigates the minimizes damage to and provides adequate protection of public health, welfare and the environment."

Clearly, according to the NCP, two factors should be considered when determining the level of aquifer restoration or individual site cleanup required at the facility. The remedial alternative chosen must be cost-effective and yet effectively mitigate and minimize damage to and provide adequate protection of public health, welfare and the environment. Using these criteria as a guideline, in conjunction with the site-specific conditions, appropriate remedial action plans for aquifer restoration and cleanup of the other sites at the facility were developed to meet the requirements contained in the agreement.

Aquifer Restoration

Due to the existence of several plumes containing one or more contaminants at the site, different cleanup levels may be specified depending upon a plume's location, flow field and contaminant transport and behavior. From previous studies, it appeared that on-

ly a portion of contaminants in the groundwater would reach the municipal wells. Other contaminants were flowing in the direction of a nearby river, downstream of the municipal wells, while other contaminants were traveling away from the municipal wells in the direction of a brook.

Using the NCP guidelines for providing adequate protection of public health and the agreement requirements of restoring the aquifer to a "fully usable condition," the appropriate level of cleanup and mitigative measures for an aquifer restoration plan at the facility would have to comply with the following:

• Aquifer restoration intercepted by municipal wells would require attainment of water quality levels, after treatment, which meet applicable drinking water standards.

• The contaminants contained in that part of the aquifer discharging to the nearby river could not exceed the river's capacity to assimilate these contaminants. This assimilative capacity comes from dilution, dispersion and evaporation.

• An Aquifer Restoration Program should incorporate the most appropriate and effective technology demonstrated for similar cases. Such technology included the removal, treatment and subsequent recharge to the aquifer. Because no quantitative predetermined levels of cleanup had been established, both of the previous conditions applied. In addition, the level of contaminant removal obtainable through treatment will be determined by the limitations of the available technology.

Other Waste Sites

The intent of remedial actions at the other sites was to control the contamination at the source before it entered the aquifer. Therefore, a remedial action which provided an appropriate extent of remedy at these sites was one that minimized the long-term infiltration into the closed site, thereby preventing the production and migration of leachate. If, however, the implementation of a remedial action caused a greater environmental or health danger than no remedial action, a no action alternative would have been appropriate.
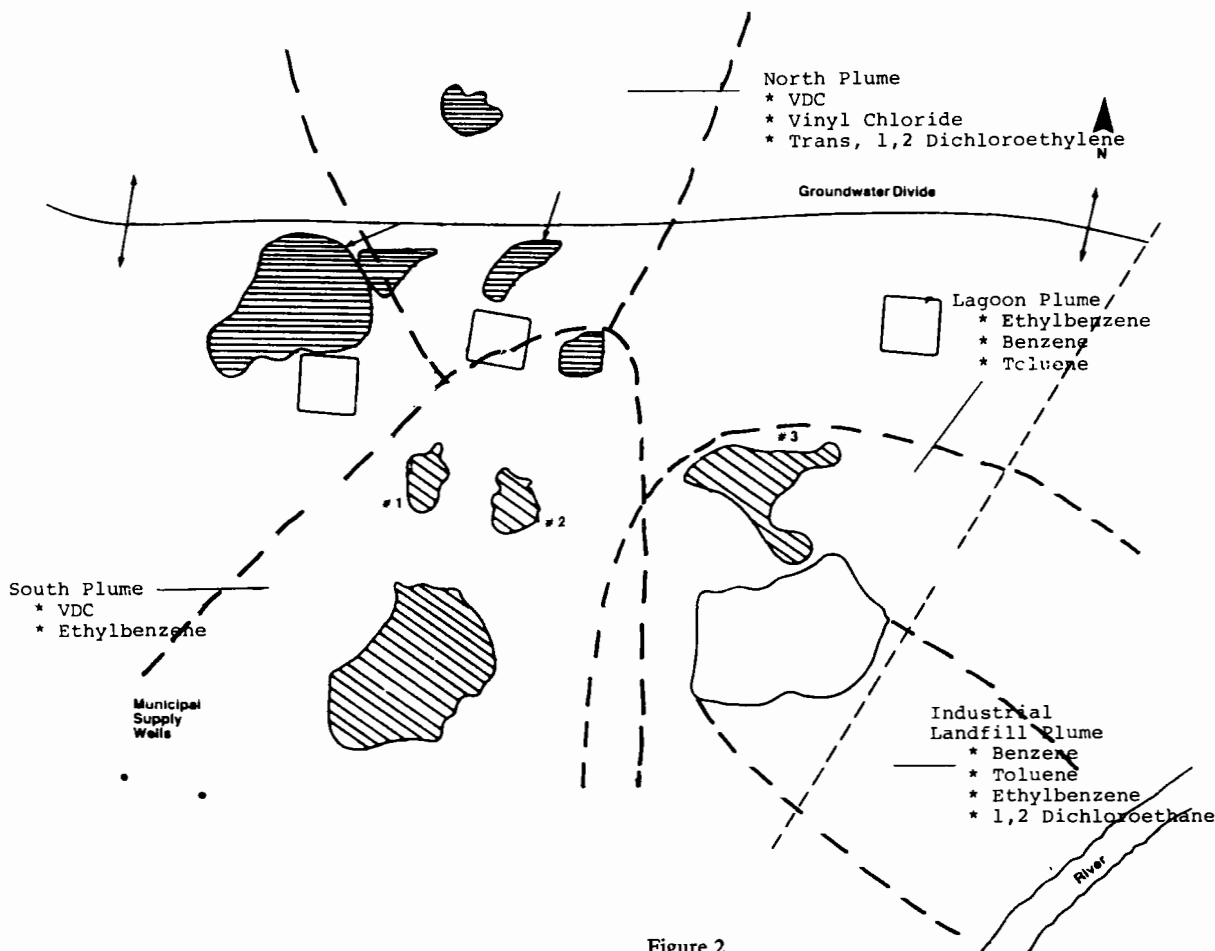
Figure 2
Groundwater Contamination Plumes

Identification of Remedial Alternatives

Aquifer Restoration

Several remedial technologies applicable for aquifer restoration were identified for preliminary screening, specifically:

•Natural and physical removal of water—natural cleansing (no additional actions with continued pumping under present conditions) or additional recovery well pumping.
•Water treatment—activated carbon or air stripping.
•In situ Treatment—biological.
•Containment Structures—slurry walls.

Other Waste Sites

The specific technologies applicable for remedial action at the other sites depended upon the nature and extent of contamination present at the individual disposal areas. Furthermore, for the purpose of remedial actions at these sites, it was decided that any off-site remedial measures which were under consideration were more appropriately addressed and implemented under the Aquifer Restoration Plan. The intent of remedial actions at the other waste sites was to control the contamination at the source before it entered the aquifer. Therefore, the following source control methods were identified for preliminary screening:

•No Action
•Capping
•Encapsulation
•Containment Structures
•Incineration
•Disposal

Evaluation Criteria

The assessment criteria used to preliminarily screen the above technologies were based on those specified in the NCP (40 CFR 300.68H). This section states that "three broad criteria should be

used in the initial screening of alternatives...," cost, effects of the alternative and acceptable engineering practices:

•Cost. For each alternative, the cost of installing or implementing the remedial action must be considered, including operation and maintenance costs.
•Effects of the Alternative. The effects of each alternative should be evaluated in two ways: (1) whether the alternative itself or its implementation has any adverse environmental effects, and (2) whether the alternative for source control remedial actions is likely to achieve adequate control of source material.
•Acceptable Engineering Practices. Alternatives must be feasible for the location and conditions of the release, applicable to the problem and represent a reliable means of addressing the problem.

Evaluation of Remedial Technologies:

Aquifer Restoration

As a result of the preliminary screening process, the following remedial actions were proposed for restoration of the aquifer:
•Physical removal
•Water treatment
•Natural aquifer cleansing

By varying and/or combining operational modifications and discharge locations of the above technologies, several remedial alternatives were developed. These consisted of various locations of bedrock extraction wells in conjunction with strategically located pumping wells and water treatment systems.

Other Waste Sites

The preliminary screening process for those technologies considered for the other sites eliminated containment structures and incineration from further consideration. Although encapsulation and solidification at individual sites were also eliminated, these actions

were evaluated further under the co-disposal option. Therefore, the following remedial actions were proposed for the other waste sites:
•No Action
•Capping
•Disposal: on-site, off-site

Detailed Evaluation

As part of the studies conducted at the sites, conceptual and mathematical computer models of the groundwater flow field and contaminants transport in the aquifer were developed. Various pumping strategies were incorporated into the model to determine the effects of these alternatives, which were used during the detailed evaluation. The recommended remedial action plan for aquifer restoration is currently under government review, while the detailed evaluation of alternatives for the other sites is ongoing.

A detailed evaluation of the proposed technologies for the other waste sites was required to determine which alternative would be most cost-effective and environmentally sound.

#2—PCB CONTAMINATION

In the second case history to be discussed here, the criteria within the NCP were also effectively used during remedial action planning for PCB-contaminated river sediment in the northeast.

In June, 1981, the USEPA, the state and a major industry signed Consent Orders which established a framework by which the company could begin to develop a program to conduct studies of PCB contamination, transport and remedial actions for the affected river and related bodies of water. The purpose of the Remedial Action Study, as stated in the orders, was to study the relative costs, benefits and environmental impacts of remedial actions or treatment of sediments so that concentrations of PCBs did not exceed 10 and 50 ppm. In addition, the company agreed to study the feasibility of the removal or treatment of sediments to PCB concentrations of 1 ppm.

Although the Consent Orders provided a broad framework of steps for developing a sampling and analysis program and recommended investigating specific remedial alternatives, they did not address the methods of response and the process for remedial action selection.

Site Description

The study area was a major river in the northeast which passes through several states (Fig. 3). Three key drainage areas along the river basin were identified in a transport study which characterized three separate reaches of the river with distinctive gradients ranging from 0.04 to 0.2%. The significance of this change in gradient is the differential effect on the flow and discharge rates for various segments of the river. These changes in the flow regime translate to a wide variety of erosional, transport and depositional environments for PCB-laden sediment which would, in turn, determine variations in PCB concentrations and the appropriate remedial action.

One of the most significant areas of study is a pond located approximately 18 miles from the disposal area. In addition to numerous shallow channels and meanders, there is a dam, a bypass channel and a holding pond. The transport and deposition mechanisms of this area were complex because of the variety of flow regimes. Deposition was compounded by several man-made structures which acted to either divert sediment around the area or trap it.

The stretch of river from the suspected source of contamination to a point 18 miles downstream has been defined as the Remedial Action Zone (RAZ). The RAZ includes those areas for which average concentrations of greater than 10 ppm occur, as prescribed in the Consent Orders. Each of these areas was, therefore, subjected to evaluation for appropriate remedial actions.

As a result of the implementation of selected engineering alternatives, the Remedial Impact Zone (RIZ) was defined as that section of the river below the RAZ which would be affected by upstream remedial actions.

Extent of Contamination

The characteristic river sections of the study area previously defined are shown in Table 1. For each of these sections, the amount of PCB, the fraction of the load and the average PCB concentration is given.

The average concentration for background stations upstream from the suspected source area was 0.15 ppm. The pond area contained a variety of flow and depositional environments and had a mean PCB concentration of 24 ppm. The range for the area was 0.09 to 100 ppm. The highest concentrations occurred in the more quiescent areas of the pond along its banks, backwater pools, oxbows and behind a submerged abutment at the head of the channel.
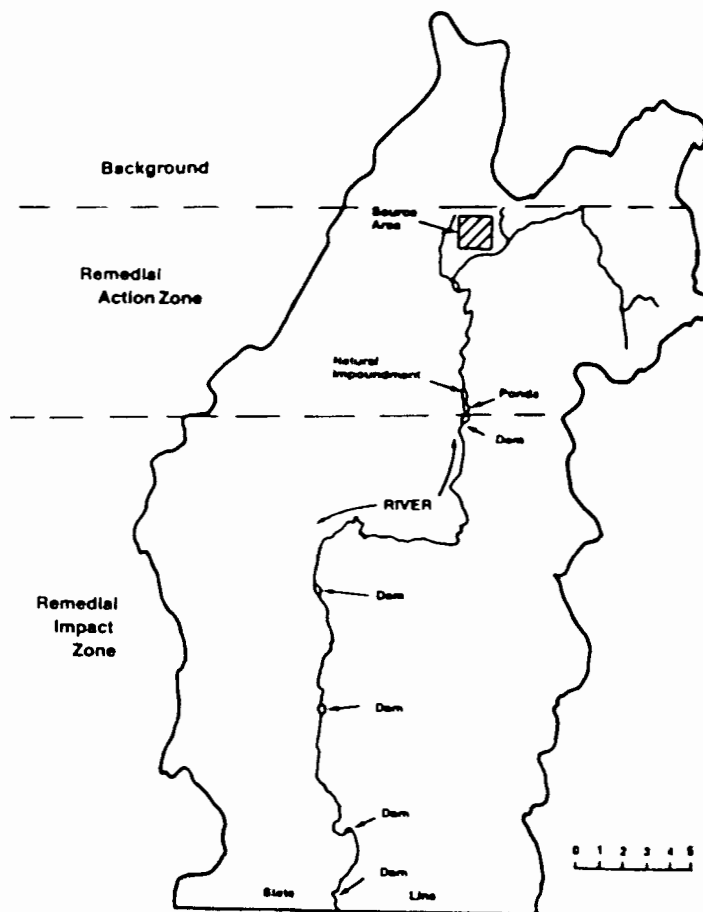

Figure 3
Outline of River Basin Area

The average PCB concentration decreased to 3.1 ppm over the next 19 mile stretch below the pond. However, this concentration was misleading due to a series of five dams along this stretch which trap sediment. The PCB concentrations behind two of the dams were 0.21 ppm and 5.9 ppm; the discharge of suspended PCBs is a factor of 10 times as great as the pond area station.

From the data contained in Table 1, several conclusions were drawn. The first and most obvious was that the natural and man-made impoundments create effective traps for sediment and PCBs. However, discharge of PCBs was highest from impounded areas of lower concentration. Therefore, remedial actions designed to reduce the PCB concentration to specified levels in certain areas were not necessarily the most effective in reducing the transport or bioavailability of PCBs in the river.

Table 1
PCB Distribution in the River

LOCATION	SECTION	LENGTH	PCB (POUNDS)	% OF LOAD	AVERAGE PCB CONCENTRATION (PPM)
Background	1	6.33	14	0.1	.15
Remedial Action Zone	2	7.8	8,510	23.1	60
	3	4.4	16,500	44.7	22
		.4	7,240	19.6	24
Remedial Impact Zone	5	19.4	3,945	10.7	3.1
	6	23.9	671	1.8	.66
TOTALS		62.18	36,880	100%	—

Identification of Remedial Technologies

The Consent Orders required the evaluation of at least four remedial actions, which were:
•No Action
•Dredging and removal of PCB-laden sediment
•In situ treatment
•In situ impoundment

Additionally, those water diversion techniques which would minimize and mitigate the re-suspension or transport of sediments were also included. These included sediment dispersal control equipment such as silt curtains or sheet piling and surface and groundwater controls such as cofferdams and slurry walls.

Evalulation Criteria

Like the previous case history, a preliminary screening of accepted remedial technologies was first required to eliminate inappropriate actions from further consideration. The remaining actions were then subject to a detailed evaluation to select the most cost-effective and environmentally sound alternative. Development of the preliminary screening criteria was based on the three broad criteria suggested by the NCP and the Consent Orders—cost, effects of the alternative and acceptable engineering practices. These criteria were used to eliminate technologies which consisted of:
•Alternatives judged not technically feasible, including unproven or conceptual methods
•Alternatives not consistent with the Consent Order
•Ineffective controls in reducing exposure to or potential health effects of PCBs
•Alternatives having conceptual costs that were not cost-effective (i.e., costs which are an order of magnitude higher than other alternatives and do not provide a commensurate environmental benefit)
•Alternatives that required an unreasonable length of time to implement due to regulatory requirements or technical issues (i.e,, permits, pilot studies)
•Alternatives which have significant adverse environmental effects

The selected methods were state-of-the-art technologies specific to the PCB problem and were based on proven application developed for other sites with similar needs.

Evaluation of Remedial Technologies

The following is a summary of those techniques retained for further evaluation after the preliminary screening:
•No Action
•Dredging of PCB-laden sediment using: clamshell, cutterhead suction, Mudcat, pneuma and namtech dredges
•Excavation of PCB-laden sediment using: scraper, front end loader, backhoe and/or dragline crane
•Sediment dispersal control using: silt curtains, floating boom and/or sheet piling

•Surface water and groundwater control using: cofferdams, dewatering, sheet piling and slurry walls
•Solids dewatering using lagoons, drying beds or container storage
•Chemical fixation
•In situ impoundment using: isolation (dikes, berms, bulkheads, sheet pilings, impermeable liners and inert material), stabilization and/or channelization
•Disposal using a landfill or incineration either on-site or off-site
•Sorbent materials

Each one of these technologies involves proven engineering practices which may be applicable to the river and may be effective in reducing the PCB concentration to the desired level. However, the following discussion evaluates two of the selected alternatives which were found to be technically feasible but required further evaluation due to their cost effectiveness and environmental impacts.

Incineration

Incineration of PCB-laden sediment is a feasible and applicable disposal action. However, the cost of incinerating PCB-laden sediment at a presently operating incinerator is high due to the low BTU value of the sediment and the high supplemental energy requirements to incinerate the sediment as required by 40 *CFR* 761.40. This greatly exceeded the cost of sediment disposal at an off-site chemical waste landfill, without providing a commensurate environmental benefit. Since the high cost for incineration is based on the energy requirements for PCB destruction, an on-site incinerator would have a comparable cost. Therefore, neither on- nor off-site incineration were considered further.

Disposal

After the removal of the contaminated sediment is complete, solids dewatering for transportation and disposal is required. The disposal of wastes containing concentrations of PCBs above 50 ppm is regulated by TSCA while materials with PCB concentrations below 50 ppm may be disposed of under other federal and state regulations.

Based on the sampling data, the sediment removal volumes required to meet the 50, 10 and 1 ppm concentration limits within the river are 243,890, 472,405 and 1,286,760 yd^3 respectively (Table 2). However, the physical separation of sediment at various concentration levels is not feasible. Also, the co-mingling of sediments to achieve an average concentration of below 50 ppm (dilution) is prohibited under TSCA. In order to remove the 10 and 1 ppm levels, the sediment with PCB concentrations above 50 ppm must be included. The distinction of sediment with less than or greater than 50 ppm would require extensive sampling and analysis prior to and during removal. Therefore, all sediment removed would be required to be disposed of at a licensed chemical waste facility.

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Assuming that a 50 ppm limit was established, the transportation of 243,890 yd³ of sediment would be required. At 12 yd³ per load, this amounts to a total of 20,325 truckloads. Using six months per year due to weather conditions and dewatering requirements, approximately 1,130 trucks per month would travel from the site(s) via local, secondary and interstate roadways.

Extensive mitigating measures would be required to reduce the many environmental risks associated with this alternative. The potential for leaks and accidental spills with such a large volume of material and traffic is inherent. The social impact of the transportation of contaminated materials through residential areas is great and has been a major determining factor at many other waste sites.

Table 2
PCB Removal from Plant to State Border

PCB Concentration Limit (ppm)	PCB Removal (lb)	% PCBs Removed	Add'l % PCBs Removed	Sediment Removal (yd³)	Increased Removal Ratio*
50	25,533	69	---	243,890	—
10	31,617	86	17	472,405	2
1	36,297	98	29	1,286,760	5

*Obtained by: $\dfrac{\text{Sediment Removal at ''X'' Concentration Limit}}{\text{Sediment Removal at 50 ppm}}$

Table 3
Sediment Removal Requirements

ALTERNATIVE	SEDIMENT VOLUME (YD³)	COST*
50 PPM	243,890	$18,291,750
10 PPM	472,405	$35,430,375**
1 PPM	1,286,780	$96,507,000**

*Cost-$75/cubic yard assuming local disposal.

**These costs do not reflect the added costs of transportation, mobilization, and establishment of additional disposal sites beyond those required for 50 ppm.

The additional cost of transportation and disposal at an off-site facility was not justified given that the same measures of protection and environmental benefit can be achieved by local disposal. Therefore, the availability of local disposal sites will be investigated during the detailed engineering evaluation. These sites are required to meet the specification of 40 CFR. 761.41.

Extent of Remedy

As previously stated, the Consent Order required the study of remedial actions necessary to meet PCB concentration limits of 50 and 10 ppm. In addition, the company agreed to study the feasibility of the removal or treatment of sediments to PCB concentrations of 1 ppm. However, the criteria which should be used to evaluate the remedial alternatives necessary to achieve these levels were not specified. The NCP guidelines were again used to determine the appropriate "extent of remedy" required during this privately financed cleanup activity. Specifically, the remedial alternative chosen must be cost-effective and effectively mitigate and minimize damage to and provide adequate protection of public health, welfare and the environment.

The estimates of PCB load and sediment removal requirements for the river from the facility to the state line are presented in Table 1. Sediment removal volumes and associated PCB removal in lbs. for the 50, 10 and 1 ppm concentration limits are included. Using this information, the percentage of PCBs removed from the river for each limit were developed and presented in Table 2.

To achieve the 50 ppm limit, a total of 25,533 lbs. of PCBs would be removed; representing 69% of the total PCBs present in the river. In addition, this requires the removal of 243,890 yd³ of sediment. Only selected sediment removal from the facility to and including the pond would be required.

In comparison, to achieve the 10 ppm limit, a total of 31,617 lbs. of PCBs had to be removed from the facility to the state border. This represented only an additional 17% of the total PCBs removed over the 50 ppm limit. In conjunction, this would require twice the volume of sediment removal or 472,405 yd³.

The 1 ppm limit would result in the removal of 36,297 lbs. of PCBs or 1,286,780 yd³ lbs. of sediment from the facility to the state border. In comparison to the 50 ppm limit, an additional PCB removal of only 29% would be achieved, requiring five times the sediment removal volume required at 50 ppm. These figures represent sediment removal volumes only. The cost-effectiveness associated with these removal volumes was also analyzed.

Assuming a local disposal facility, the cost to remove and dispose of PCB-laden sediment has been approximated to range from $50-$100/yd³. Using an average of $75/yd³, the disposal cost would be $18,291,750, $35,430,375 and $96,507,000 to meet the 50, 10 and 1 ppm limits respectively (Table 3).

Based on the foregoing analysis, it was determined that the removal of the total sediment volumes required to meet the 50, 10 and 1 ppm limits was neither reasonable nor cost-effective. This did not preclude, however, the possibility of limited removal from selected areas of sediment with PCB concentrations greater than 50 ppm, where other remedial measures are ineffective in mitigating environmental and public health impacts. Therefore, removal of total sediment volumes required to meet the 10 and 1 ppm limits were not evaluated further.

The NCP criteria were used as a guideline to determine the extent of remedy required for PCB removal along the river as the 50 ppm PCB concentration level was determined to be the most appropriate level of cleanup in this case.

Government approval has been given to the above evaluation. Currently, remedial action planning for only those areas with PCBs greater than 50 ppm is being conducted.

CONCLUSIONS

The two case studies presented in this paper outline how the criteria set forth in the NCP provided guidance during the remedial action planning at several hazardous waste sites. In each case, the settlement documents agreed upon by the responsible parties provided little decision-making criteria from which remedial alternatives could be assessed nor did they address the question, "How clean is clean?" The NCP provided the specific guidelines used to define the appropriate extent of remedy required at these sites as well as to evaluate, screen and select the most cost-effective and environmentally sound remedial alternatives.

EFFECTS OF UNCERTAINTIES OF DATA COLLECTION ON RISK ASSESSMENT

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INTRODUCTION

The primary purpose of site characterization is to provide a data base for use in determining whether a problem exists, the nature and extent of the problem vis-a-vis potential remedial actions and the resulting risk contaminants on the site pose to human health or environmental systems. The primary means for evaluating the current situation is to compare concentrations of chemicals in samples obtained from within environmental pathways, measured at or extrapolated to the point where receptors would be impacted, with human health risk levels and/or established environmental standards. Evaluation of both risk and feasible remedial actions, however, should also consider past and future potential impacts. Such considerations require data for understanding contaminant sources and the mechanisms by which chemicals are, or would be, transported from a source to a receptor.

The uncertainty in data acquired at a hazardous waste site is often neglected in assessment of observed or potential risks. For the simple case of evaluating risks posed by exposure of receptors to chemicals, the risk analysis will be limited by the degree of confidence in contaminant levels as determined by sampling and analysis. For determining mechanisms of source release and transport and for evaluation of potential impacts and remedial action efficiencies, uncertainties in data on source release, migration and contaminant levels at receptor sites all affect the assessment.

In this paper, the authors discuss the uncertainties inherent in geohydrologic and chemical analytical field data, with consequent effects on risk analysis and decision making. The uncertainties and errors that can be introduced by computations, statistical analysis or mathematical simulation have been ignored; we have assumed that the computation and interpretation methods are conservative, and any errors in data will carry forward to the assessment.

UNCERTAINTIES IN GEOHYDROLOGIC DATA

Because groundwater impact is a major concern at most hazardous waste sites, understanding flow in groundwater systems is a prerequisite for predicting contaminant pathways and rates of migration. Although flow patterns can be determined using theoretical methods (e.g., analytical, numerical or physical models), empirical methods based on laboratory and field measurements of hydrologic parameters are the most commonly used approach in hazardous waste migration studies. The direct approach is most appropriate because of the scale and precision required for the limited areal extent typical of the study sites.

Measured parameters can be grouped into spatially variable parameters and parameters that are both spatially and temporally variable. Hydrologic parameters that are spatially dependent include:
- Horizontal hydraulic conductivity or transmissivity
- Vertical hydraulic conductivity or leakage
- Coefficient of storage or storativity
- Porosity, specifically effective porosity
- Specific yield and retention

Those variables that are also temporally dependent include:
- Stress (recharge and discharge)
- Potential or hydraulic head

The latter three spatially-dependent parameters generally have the smallest ranges and have more easily measurable and predictable properties than hydraulic conductivity. Hence, they have the least uncertainty. For example, in unconfined aquifers of porous media, values for storativity typically range from 0.05 to 0.25. In unconfined aquifers, storativity is the same as specific yeild, which is a parameter easily estimated from published values.[1, 2] The specific yield is approximately equal to the porosity or effective porosity for more permeable materials. In any case, substituting specific yield values is a useful and inexpensive method for estimating storativity and effective porosity from geologic samples or lithologic descriptions. Because the spatial variability of these three hydrologic parameters is relatively small, the potential undertainty is quite small. In fact, an experienced hydrogeologist can usually select a representative set of values based on lithologic data alone that rarely is in error greater than a factor of one.

While these parameters may be reliably determined for unconfined porous media, obtaining accurate values in confined systems and fractured media is more difficult. Storativity values for confined aquifers may range from 0.00001 to 0.001, and the range would be even greater for fractured media.[3] Values for effective porosity and specific yield are still easily estimated for confined porous media; these parameters are most difficult to predict in fractured rock, particularly if transmissivities are low.[4] Collection of representative data is difficult and costly, and the applicability of data collection methods is limited.[5] Even when field procedures and measurements are precisely controlled and accurate within ±2%, the actual value obtained may have large uncertainties.[4, 6] Despite these difficulties, uncertainties in the values obtained are small compared to uncertainties in hydraulic conductivity.

Hydraulic conductivity or transmissivity determinations almost always require direct measurements to confirm preliminary estimates or indirect measurements.[7, 8] Direct subsurface measurements require an access port, i.e., a monitoring well. Thus, a monitoring well must be designed to allow reliable and representative measurement of hydraulic conductivity, potential and chemical

quality of groundwater. The importance of monitoring well design and configuration on accuracy, resolution and representativeness of data has been well-documented.[9, 10, 11, 12, 13] Aspects which affect the uncertainty of data are discussed below.

Well Diameter

Transmissivity and storativity values obtained from small-diameter monitoring wells are less representative, and the data uncertainties are greater than for measurements on larger diameter wells. In a recent example, transmissivities obtained from tests on 2 in. diameter wells were shown to be in error by up to two orders of magnitude. The higher chemical and potential data density possible through use of small-diameter wells[15, 16] must be balanced against the need for data on other properties affecting migration.

Screened Interval

Depth and selection of length of the screened interval must consider the probably pathways for contaminants to enter into and move through the saturated zone. Vertical placement and length of the monitored interval must consider both hydrostratigraphic equivalency and chemical properties of the contaminants.[17]

Materials of Construction

Materials used for casing and screen have only minor effects on uncertainties in hydrologic parameters[18] but may have a large effect on chemical data. Leaching of constituents from the well materials, or adsorption of contaminants onto the materials, can occur.

Installation Techniques

Improper drilling and installation methods can drastically affect the measured transmissivity, resulting in errors of up to a few orders of magnitude.[17, 19, 20] The most common installation problems are alterations of the formation via drilling methods (mud rotary drilling was recently shown to seriously affect subsequent transmissivity measurements) and inadvertent hydraulic interconnection between distinct hydrostratigraphic units. Also, failure to adequately develop a well may result in transmissivities with a high degree of uncertainty.[17, 21]

Hydraulic Potential

Hydraulic potential is obtained by direct field measurement, and uncertainties can result from inaccurate measurements of water level and ground surface elevation.[22] The principal uncertainty in potential data, however, relates to the degree of hydrostratigraphic and time equivalence of the measurements. Uncertainties in interpretation of potential data can be equal to or greater than the hydraulic gradient, leading to gross misinterpretation of flow direction.

Transmissivity

Transmissivity or hydraulic conductivity can be determined by laboratory methods. Olson and Daniel[23] compared field and laboratory hydraulic conductivity (K) values from the literature and found that field results are usually higher than laboratory results for the following reasons:
- Laboratory tests were usually performed on more clayey samples
- The presence of sand seams, fissures and other macrostructural features are not represented properly in laboratory tests
- Laboratory K values back-calculated from consolidation theory were often used instead of directly measured values
- Vertical flow K is usually measured in the laboratory, whereas horizontal flow generally occurs in the field
- Distilled water is normally used in the laboratory tests
- Laboratory samples often have air entrapped in the sample

Other sources of error in laboratory testing include: voids formed during sample preparation, smear zones, growth of micro-organisms, use of excessive hydraulic gradients and temperature effects. A large uncertainty in hydraulic conductivity or trans-

missivity can be expected if reliance is made on laboratory-derived values.

While field testing to measure hydraulic conductivity or transmissivity may eliminate many of the problems associated with laboratory tests, other potential errors can be caused by:
- Unrepresentative values caused by inappropriate drilling techniques or well construction methods as discussed above
- Inadequacy of the test method to provide data on heterogeneity, anisotropy or storativity of the aquifer and confining units
- Use of simplistic conversion factors in calculating transmissivity
- Use of a formula to calculate transmissivity or hydraulic conductivity which is inappropriate for the actual field conditions

Any deviation in field conditions from the theoretical conditions assumed in derivation of a formula will lead to some amount of error in the computed values. These deviations should be taken into account when final evaluation of the field test data is made. In practice, the formulas have been applied with success and the calculated hydraulic characteristics have proven to be reliable for most purposes.[24] Uncertainties in field data of the type discussed above, however, will be transmitted through any calculations.

UNCERTAINTIES IN CHEMICAL DATA

The uncertainties in the concentration of various chemical species at or neat sources, within environmental pathways or at points of exposure depend on two factors:
- The uncertainties in collection of representative samples from sources, environmental pathways or exposure points and presentation of the samples for chemical analysis
- The uncertainties in determination of the constituency of samples that will define health or environmental risks

Sampling Methodology Uncertainties

Sampling involves the acquisition of a small piece of the environment that is representative of the entire matrix to be considered in risk analysis in such a manner that the representativeness is not compromised. When performed in site investigation programs with limited budgets and schedules, sampling is beset with uncertainties both in theory and in practice. Statistical analysis may require many replications of data before confidence limits become acceptably small. Methods accounting for data variability require an even larger data set over the parameter space. In the authors' experience, neither time nor funds are usually available for the extensive sampling efforts needed to establish a high degree of confidence in, and tight confidence bounds on, environmental data. A single sample is used more often than replicates as the basis for a risk analysis, and the very low confidence that results is usually ignored.

A particular case where sampling theory is at odds with budget and schedule involves neglect of factors known to affect the validity of risk analyses but requiring extensive field data for complete definition. In a recent example, careful and replicate procedures were employed to precisely define the chemical profile within a soil column. Following this determination, the results were corrected by an assumed soil-water partition coefficient (perhaps valid to within 1-2 orders of magnitude) for comparison with an established health risk water criterion. Although the uncertainty in the resulting assessment was recognized, no attempt was made to validate the assumption, because the soil partitioning experiments would have forced a delay in site assessment of at least several weeks. In effect, the exacting soil column sampling was wasted effort and did not enhance the certainty of the assessment.

In any sampling design, the relative uncertainty of all factors in a risk analysis needs to be considered because the uncertainty in the analysis can be no less than that of the least certain factor. Available time and funds would be better spent in determining factors with the greatest degree of uncertainty and with the greatest impact on the overall uncertainty of the assessment.

Sampling Procedure Uncertainties

Uncertainties and biases in the sampling procedures can have a significant effect on data assessment. Some obvious factors, as well as concepts which may not be obvious to site investigators, are considered below. Because site characterization efforts generally involve collection of groundwater samples, the discussion focuses on this type of sample.

Collection of groundwater samples from an appropriately-designed monitoring well network would seem to be relatively straightforward; procedures are generally specified in most site investigation programs. However, there are a number of instances where generally acceptable procedures can be inadequate or can result in gross uncertainties in assessment data. Several cases that are frequently encountered during site investigations are considered below. The possible uncertainties for two of the cases (inadequate purging of wells and cross-contamination) are considered in detail.

Inadequate Well Development and Purging

Drilling and completion of monitoring wells represents extreme disturbance of the natural groundwater matrix. Development or purging of wells is essential to remove foreign materials introduced during the drilling and to restore the groundwater to reasonably representative conditions. Similarly, wells should be purged immediately prior to sampling to remove water in the well bore and the formation immediately surrounding the well bore. In either case, approximately 5 equivalent volumes (EV) are typically removed, and even this quantity is often not removed for wells of very low yield.

To consider the uncertainties introduced by inadequate well development or purging, we have calculated possible residual effects after removal of 5 EV from a typical well of 8 in. borehole diameter, 4 in. casing diameter, 15 ft sand pack (30% porosity), 10 ft screened interval and 30 ft water column. The volume of standing water (1 EV) is 3.8 ft^3 (107.5 L) and 5 EV is 538 L. For contaminants introduced by the drilling process, or for variations in chemical composition between the open well and the formation, a dilution factor of 538 can be expected between the volume purged and the typical 1 l sample collected for analysis. If the action level for a contaminant is 1 µg/l (criteria for many contaminants are even lower), the criterion in the sample would be exceeded if only 538 µg of contaminant were introduced during the drilling or sampling process. Drilling would involve removal of about 3 x 10^5 g of formation material from just the sand-packed region, and sampling would involve purging of about 5 x 10^5 g of water. Based strictly on a materials-handling concept, the odds against avoiding introduction of 538 ug of "foreign" material are 6 x 10^8 and 9 x 10^8 for drilling and sampling, respectively. In practical terms, the removal of 5 EV during development or sampling could be totally inadequate for providing data with a high degree of certainty.

Similar considerations apply, in reverse, if clean water is introduced during drilling into a highly contaminated aquifer or if sampling for volatiles (which escape from the water in an open well) is attempted. For these cases, the measured concentrations following purging will be lower than those of the natural matrix.

It is apparent that any reasonable degree of well development or purging will not assure removal of foreign materials introduced during drilling or sampling. The authors recommend a number of procedures to minimize the problem:

Purging

Greater dependence should be placed on natural purging of monitoring wells. A considerable period of time should transpire between well completion and sampling. For most aquifer systems, 2 to 4 weeks prior to sampling is inadequate. If the groundwater flow rate can be estimated, then the time required to exchange water within the well bore can be calculated. For the typical well considered above, and a typical flow rate of 0.5 ft/day, the time required to purge 100 EV via the natural groundwater flow would be 76 days. If the schedule permits, a waiting period of 2 to 3 months would be recommended before sampling the well. An ad-

vantage of natural purging is that no hazardous wastes are generated, as is often the case for water removed from contaminated wells.

Sample Series

A series of samples should be obtained from the well over a period of time. The presence of induced contamination can be derived from the change in analytical data with time. The possibility that natural changes in groundwater contaminant levels are occurring, however, may require collection of several samples so that the contribution arising from induced contamination can be calculated.

Induced Contamination

The possibility that low levels of contaminants could be due to induced contamination should always be considered in risk assessments. Given an understanding of the source location and the hydrologic system, the uncertainty in the risk analysis from this factor can be calculated. In general, the degree of uncertainty will be high for a small number of samples acquired shortly after well completion and limited development.

Cross Contamination During Sampling

The potential for inducing foreign materials into a well via sampling equipment should always be considered. Sampling of any well after sampling of highly contaminated wells increases the potential for cross contamination. At one hazardous waste site investigated in 1983, the authors observed contamination in wells ranging from essentially pure methylene chloride (1,330 g/l) down to the detection limit of about 2 µg/l. The amount of pure methylene chloride that would need to be transferred to the typical well to produce 2 µg/l after purging of 5 EV (538 L) is 8 x 10^{-7} l, or about one-tenth of a drop.

Considering the potential for cross contamination and the difficulties involved with stringent decontamination of sampling equipment in the field, the authors recommend the following procedures:

- Individual sampling equipment, including bailers and pumps, should be used in each well. No sampling equipment should be transferred between wells.
- Field operational planning should specify sampling of wells in order of increasing expected concentrations of contaminants. For highly contaminated wells, sampling equipment should be discarded after use and not reused.
- The uncertainty arising from potential cross contamination should be factored into any subsequent risk assessment.

Other Elements of Uncertainty

A number of other potential problems associated with sampling and analysis must be considered in evaluating the uncertainty of risk assessments:

If fracture flow and circuitous flow paths of groundwater are suspected, analytical data from any given well may be highly uncertain for assessing contaminant migration. For such cases, the chemical data may make no sense until the major flow paths have been defined.

To evaluate the quality of the entire sampling and analysis protocol, QC samples should be introduced into sampling lots in the field. However, this practice is difficult to implement with a high degree of certainty. The authors have observed benzene at 33 µg/l in distilled water used for field blanks.

Sampling methods employed require consideration of the types of analytes; the use of most pumps and bailers can result in loss of volatiles, and aeration of samples may enhance aerobic chemical or biological transformations. A detectable loss of volatiles and phenols from samples has been observed after using even low-energy bladder pumps in monitoring wells.

Filtration of samples can result in large uncertainties; the potential for cross contamination is increased, and contaminants can be adsorbed onto the filter body and filtration medium. The authors have observed considerable loss of phenols from water samples during filtration, due to absorption onto filters.

Preservation, shipping and storage of samples prior to analysis are important considerations. Possible effects include chemical and biological degradation as a result of the unnatural state of bottled samples and the potential for adsorption of contaminants on container wells. The authors have observed degradation, and considerable adsorption onto glassware, of phenols within a few hours after sampling.

The very small quantity of contaminants required to produce detectable concentrations can be introduced into water samples via air transport. The authors have observed detectable levels of aromatic hydrocarbons in wells that were traceable to use of a pump driven by a gasoline generator.

A major problem with soil, sediment or waste samples is the difficulty of achieving representativeness. Even when extreme precautions are taken during collection, grinding, sieving and subsampling, large uncertainties can be avoided only by analyzing a large number of samples.

Cross contamination during solids sampling is highly probable unless stringent equipment decontamination and elaborate procedures are employed. A high degree of uncertainty is expected for samples collected from a soil boring because of the potential for cross contamination.

Analysis should be performed on solid samples in the wet state. The practice of air drying samples before analysis results in loss of volatile and semivolatile compounds and increases the potential problems with chemical and biological degradation many-fold.

Despite elaborate procedures and extreme care in conduct of sampling and analysis, considerable uncertainty in analytical data will remain. Most analytical methods will provide data that are, at best, good only to within ±10-20%. The validated analytical uncertainty should be carried forward as a "best case" for the risk assessment and remedial action analysis.

CONCLUSIONS

The considerable effects that arise from uncertainties in field data should be considered in any subsequent assessments and decisions. The potential for uncertain results should be quantified and considered in planning of field efforts. The manner in which field work would be conducted to minimize uncertainties in subsequent assessments is at odds with typical schedules and budgets for site investigations.

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AN EPIDEMIOLOGIC STUDY OF COMMUNITY EXPOSURES TO 2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN

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CHARACTERIZATION OF ENVIRONMENTAL CONTAMINATIONS

In 1971, approximately 29 kg of 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (TCDD)-contaminated sludge wastes, which originated as a byproduct of hexachlorophene production in a southwest Missouri plant, were mixed with waste oils and sprayed for dust control in that part of the state. Two hundred forty-one residential, work and recreational areas (including several horse arenas), including the town of Times Beach, were thought to be contaminated. As of January, 1984, 36 sites have been confirmed as having at least 1 ppb of TCDD in soil, 98 have not shown contamination at this level and an additional 107 are still under investigation. Levels as high as 35,000 ppb were originally measured in soil at one of these 36 sites; current isolated levels as high as 1,900 ppb exist in these contaminated areas, but most detectable levels in soil samples range from less than one ppb to several hundred ppb.

About half of the 36 confirmed sites are contaminated with peak levels in excess of 100 ppb; 11 of these (69%) are in residential areas. These sites vary widely in their potential for leading to human exposure due to the lack of uniformity in geography, topography, geology and characteristic land use. This variability has presented difficulties in the public health policy decision-making process. Sites which have high levels of contamination and are in areas of frequent and regular access constitute the greatest public health risk. At other sites, however, dioxin contamination is in clearly circumscribed areas, at subsurface depths exceeding 15 ft, under paved areas or in areas with limited land use. All of these considerations were taken into account in assessing the risk of exposure for an estimated 4,600 individuals from these contaminated areas from 1971-1983.

The earlier phases of this investigation focused on several sites in eastern Missouri; later activities included all 36 contaminated sites. The Centers for Disease Control (CDC) had previously worked with the Missouri Division of Health (MDH) in 1971 at the time the initial contaminations occurred after receiving a report of an exposed child who presented with hemorrhagic cystitis; in 1974, this work culminated in the laboratory identification of TCDD in the waste oil. With further discoveries of widespread contaminations in mid-1982, MDH and CDC in consultation reinitiated public health activities on the basis of new information and additional environmental data.

RISK TO HUMAN HEALTH

The case of dioxin illustrates many of the difficulties encountered in assessing health risks following long-term, low-dose exposure to environmental chemical contaminations. As yet, there is no reliable, widely available method for directly measuring dioxin levels in humans. In this investigation, the lack of any direct measure of body burden substantially hindered attempts to assess the degree of exposure to and concomitant health risk posed by environmental dioxins.

Exposure Assessment

Therefore, the long-term risk of exposure in any area contaminated with dioxins must be determined by considering the excess risks of developing specific adverse health effects as a result of an estimated total cumulative dose. This dose is a function of several factors: (1) the concentration of environmental contamination, (2) location of and access to contaminated areas, (3) the types of activities conducted in contaminated areas and (4) duration of exposure. These assessments were concerned primarily with health risks in regard to contamination of soils in residential areas.

To estimate exposure, the authors made assumptions regarding the bioavailability and absorption of TCDD from soil as well as other metabolic parameters. Moreover, principal routes of uptake were thought to be through dermal absorption, ingestion and inhalation of contaminated dirt/dust particles.

Risk Assessment

Animal studies have shown great species variability in both acute and chronic responses to TCDD exposures; where humans fit on this response scale is not clear. However, common findings from both animal toxicological work and limited data on cases of high dose, exposures of humans have indicated prominent effects on several organ systems: liver changes include diminished function, hepatocellular necrosis, tumor induction (in animals) and microsomal enzyme induction; other effects include chloracne, depressed cell-mediated immunity and peripheral neuropathy. Additionally, some studies have suggested that occupational exposures to TCDD may induce an excess risk of developing soft tissue sarcomas, but the only adequate dose-response data available for use in the risk assessment calculations were from animal carcinogenicity studies. A linear, nonthreshold dose-response model was used to calculate increased lifetime cancer risk, and the calculation methods incorporated guidelines that a group of outside consultants recommended to CDC.

Risk Management

Based on these calculations, the authors concluded that residential soil TCDD levels of $\geq$ 1 ppb pose a level of concern for de-

layed health risks. In highly contaminated areas (areas with soil contamination levels $>$ 100 ppb), with a high degree of access and concomitant exposure, the estimated incremental lifetime cancer risk may increase rapidly and be orders of magnitude higher than 1 per million. Therefore, MDH and CDC issued advisories which stated that the continued, long-term exposure to persons living in specified residential areas with 1 ppb or more TCDD contamination in the soil posed an unacceptable health risk.

These public health advisories and USEPA's consideration of the available remedial options were the basis on which site-specific decisions to eliminate or mitigate these exposures were made. The time frame for such decisions was dependent on the degree of contamination and on the degree to which continued exposures could be prevented while temporary or permanent remedial actions were considered and/or executed. In most cases, the USEPA opted for temporary environmental cleanup, stabilization or restriction of access to contaminated areas because of limited, well-defined areas of contamination, relatively low TCDD soil levels or relative inaccessibility of contaminated areas. However, in several noteworthy situations (such as the case of Times Beach), it was decided that permanent relocation of residents was the most prudent action.

PUBLIC HEALTH ACTIVITIES

In addition to ongoing review and assessment of EPA environmental sampling data, MDH and CDC began four distinct public health actions in January, 1983:
- *Providing health education for both the medical and public health community and the general public about current understandings of the health effects of dioxin exposures.* A summary of the medical/epidemiological literature was prepared and sent to physicians in eastern Missouri. On Jan. 18, 1983, experts from government, academic institutions and industry were brought together to give a seminar for the local medical community. Individual consultations and toll-free hotlines were established to answer questions from and concerns of the general public.
- *Providing a dermatologic screening clinic to the general public.* This clinic was intended to screen for cases of chloracne as an indication of possible dioxin exposure. In February, 1983, on consecutive weekends, all residents of eastern Missouri who had reason to suspect that they had been exposed and who had current skin problems were invited to be seen at these screening clinics.
- *Creating and maintaining a central listing of potentially exposed individuals.* This listing will enable public health agencies to keep in touch with and locate potentially exposed individuals for educational purposes or possible epidemiologic and/or clinical follow-up. Specifically, when a reliable screening method for TCDD in serum becomes available, we will be better able to assess their exposure status and concomitant health risks. Baseline and identifying information was collected in the form of a Health Effects Survey questionnaire designed to elicit information on possible routes of exposure, life-style habits, residential histories, occupational histories and medical histories. It was also intended to serve both as a screening tool for identifying a "highest risk" cohort on whom intensive medical evaluations were focused and as a method of compiling a community-based data set from which epidemiologic inferences might be drawn.
- *Designing and implementing a pilot medical study of a "highest risk" cohort.* This research was conceived as a pilot study of a group of persons presumed to be at highest risk of exposure to environmental TCDD. It was intended to provide preliminary information on possible health effects from these exposures to enable investigators to develop more refined and specific epidemiologic protocols to be used in further investigations.

INVESTIGATIONAL METHODS

In this study, the authors assessed potential health effects related to dioxin exposures by three means. First, as previously mentioned, a Health Effects Survey questionnaire was developed to elicit information on each person's exposure risk, medical history and potentially confounding influences. The authors sought data for individuals believed to be at risk of exposure because they lived near, worked at or frequently participated in activities near a contaminated site.

Second, a dermatology screening clinic was held.

Third, the authors reviewed approximately 800 completed questionnaires and selected 122 persons for inclusion in a pilot medical study. A selected high-risk group of 82 individuals reported:

- Living or working in TCDD-contaminated areas or
- Participating on an average of more than once per week in activities that involved close contact with the soil (such as gardening, field/court sports, horseback riding, playing in soil) in TCDD-contaminated areas with TCDD levels of between 20 and 100 ppb for at least 2 years or levels greater than 100 ppb for at least 6 months. A low-risk comparison group of 40 persons reportedly having had no access to or regular high-soil-contact activities in any known contaminated areas was also selected.

Of the 122 persons in the study group, 17.1% of the high-risk group and 10.0% of the low-risk group either refused to participate or failed to appear for the examinations (this difference was not significant at the 0.05 level), yielding a study population of 104 (68 at high risk and 36 at low risk of exposure).

In addition to being compared according to their responses on the Health Effects Survey questionnaire, these 104 persons were assessed under a clinical protocol that included the following elements:
- Physical examination
- Neurologic examination
- Dermatologic examination
- Laboratory analyses
- Immune Response Tests
- Serum for use in TCDD analyses when such tests become available

RESULTS

The high- and low-risk groups were comparable in terms of age, race, sex, education of head of household and interview respondent distributions. The two groups did not differ significantly in reporting other potential sources of exposure or the use of prescription medicines. In regard to potentially confounding factors (such as employment in hazardous occupations or service in Vietnam), there were no differences. The only significant difference in life-style habits was that the high-risk group reported exercising more regularly (<0.01).

The authors found no differences or consistent trends regarding the prevalence of specific generalized disorders as reported in the questionnaires, the results of the general physical examinations or the routine hematology tests (except for a higher mean platelet count and a nonsignificant trend of diminished peripheral pulses in the high-risk group).

No consistent overall trends or statistically significant individual diagnostic differences were detected for reproductive health outcomes from the questionnaire material. No birth defects were reported among children born to women in the high-risk group after the time at which exposures could have occurred.

In the dermatologic screening, no cases of chloracne were seen in the 140 persons examined or in the 104 persons in the study population. In addition, no significant differences in dermatological findings were demonstrated by either medical histories or physical examination for the study population.

Results of the neurological examinations showed no significant differences or patterns between the two groups for the self-reported neurological conditions or from the neurological examinations.

As reported in the medical histories, there were no differences in prevalence of immune disorders. On physical examination, the only significant difference noted was a suggestion of a greater prevalence of palpable nodes in the low-risk group. Laboratory analyses showed no differences between the two groups in regard to total

induration in response to the antigenic skin tests, the *in vitro* lymphocyte proliferative responses or in comparisons of parameters from T cell subset assays.

In regard to the hepatic system, no trends or significant specific problems were reported in the medical histories. On physical examination, there was a greater prevalence of hepatomegaly in the high-risk group, but this finding also was not statistically significant. There were no statistically significant differences between the two groups on tests of hepatic function. More specifically, the two groups showed no difference in urinary porphyrin patterns, and no cases of overt porphyria cutanea tarda (PCT) or any precursor conditions (latent PCT or Type B porphyria) were detected.

There appeared to be a trend of increased urinary tract problems among the high-risk cohort on the basis of the medical history section of the questionnaire, although no statistically significant differences were demonstrated. Urinalyses also suggested a consistent pattern of abnormal findings, with a non-statistically significant higher prevalence of leukocyturia ($>$ 5 WBC/hpf) and microscopic hematuria ($>$3 RBC/hpf) in the high-risk group.

DISCUSSION

The analyses did not produce any firm indications of increased disease prevalence directly related to the putative exposures. These results do, however, offer some insights and leads for further study. Of interest is the apparent trend indicative of urinary tract abnormalities in the high-risk group, especially in light of the previously reported finding of hemorrhagic cystitis in an exposed person. The findings of no significant differences in liver function are important; however, hepatic function should be examined in subsequent studies because of other data suggesting hepatotoxic effects of TCDD.

Although none of the findings from the immune function tests and assays demonstrated statistically significant differences, several results such as the indication of an increased prevalence of helper were of note: suppressor T-cell ratios $<$ 1.0 in the high-risk group, although the functional tests of the immune system revealed no overall abnormalities. In light of the rapidly evolving work in this area, follow-up and/or further investigation of these effects in exposed cohorts should be conducted before drawing conclusions.

Several factors could explain at least part of the overall negative findings:
- The power to detect significant differences was restricted by the relatively small sample size
- A large percentage of the pool of persons from which the study and comparison groups were chosen was self-selected, thereby introducing potential biases
- Because of the absence of an objective direct measure of exposure status, the possibility of individual misclassification errors exists
- Inability to detect effects with long latency periods or subtle health effects for which our tests were not sensitive
- It is conceivable that uptake of dioxin from contaminated soils was generally less than estimated for this study group
- Chronic exposures to environmental TCDD have actually induced little or no adverse health effects

CONCLUSIONS

These actions represent the first phase in the investigation of dioxin contaminations in Missouri. The involved public health agencies continue to review environmental sampling data on new suspected sites and develop public health advisories. Although the results appear to be largely negative, no overall definitive conclusion should be based just on the initial pilot study. More refined epidemiologic studies employing different designs and strategies are planned to test the results of this pilot study. Concurrently, research into replicable laboratory methods for measuring TCDD body burden or other direct indices of exposure will be pursued.

Finally, public health policy in situations such as this environmental contamination with TCDD must continue to be focused on the prevention of any potential health effects, even if such effects were not demonstrated in a small pilot study. For this reason, all appropriate efforts need to be made to prevent human exposure.

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THE APPLICATION OF QUANTITATIVE RISK ASSESSMENT TO ASSIST IN SELECTING COST-EFFECTIVE REMEDIAL ALTERNATIVES

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INTRODUCTION

The Western Sand and Gravel (WSG) site in Burrillville, Rhode Island was ranked 128 on the National Priorities List published in September 1983. Hazardous wastes are migrating from the site via groundwater and surface water and are contaminating nearby domestic drinking water wells, a major groundwater aquifer and the Slatersville Reservoir which is designated as a Class B surface water body. The objective of this study was to evaluate the feasibility for groundwater remediation and to identify cost-effective remedial alternatives which would minimize public health and environmental risks.

SITE HISTORY

The WSG site (Fig. 1) is located in a semi-rural area of Burrillville, Rhode Island, adjacent to the Douglas Pike and close to the North Smithfield town line. This site was originally a gravel mining operation, however, beginning in 1975, a portion of the 12 acre site was used for the disposal of septage and chemical wastes. The wastes were dumped into unlined seepage lagoons and allowed to infiltrate into the soil, percolate through the permeable soils and enter the groundwater.

The available hazardous waste manifest records indicate that approximately 470,000 gal of chemical wastes were dumped at WSG from May 1978 through April 1979. No records were available to quantify the wastes dumped at the site prior to May 1978. The site was closed in May 1979.

The USEPA undertook an emergency cleanup program at WSG in 1980. Liquid chemical wastes and sludges were removed from the site and sent to licensed disposal facilities. It was estimated that 60,000 gal of waste were removed from WSG during the cleanup program while approximately 400,000 gal of waste remained.

HYDROGEOLOGIC SETTING

The topography of WSG generally results from a combination of Ice Age landforms and modern day gravel mining operations. Subsurface natural deposits are stratified drift having a glacio-fluvial and ice contact origin. These deposits consist of gravelly or sandy sediments which were deposited by meltwater streams associated with the deglaciation of the region. These sediments are a part of the Slatersville Aquifer.[1] Strata on either side of Tarkiln Brook are finer grained, slightly younger glacial sediments primarily represented by stratified fine sands.

The WSG site is located on the east side of an irregular bedrock valley with depth to bedrock varying from 30 to 70 ft below the land surface. The apparent centerline of the bedrock valley tends north-south in a direction paralleling the Tarkiln Brook. The bedrock trough is not evident near the Slatersville Reservoir, and there is a dip in the bedrock surface to the southwest.

The source of groundwater on-site is infiltration of precipitation and lateral groundwater flow from the south and east. Groundwater flow from the site is to the west and north toward Tarkiln Brook and the Slatersville Reservoir. During its flow through the site toward the Reservoir, the Tarkiln Brook is recharged at the rate of 12,000 gal/day.

EXISTING CONTAMINATION

Large quantities of hazardous wastes still remain at WSG. These wastes are found in the groundwater, in the surface water of the Tarkiln Brook and in surface and subsurface soils. There is also a layer of nonaqueous phase liquids floating on the groundwater surface in the vicinity of the groundwater pumping system at the site. These hazardous wastes (Table 1) represent a continuing source of contamination for both groundwater and surface water.

There is, however, no indication that airborne emissions of vapor or particulate from WSG are affecting the areas surrounding the site. No volatile emissions were detected at the site perimeter during a site survey using direct reading instruments (HNu Photoionization detector).

STATUS OF REMEDIAL ACTIVITIES

The Rhode Island Department of Environmental Management (RIDEM) has sponsored several studies to evaluate on-site conditions at WSG and implemented programs to reduce the migration of hazardous wastes from the site. Work programs to date have included:
- Hydrogeologic investigations
- Bedrock contamination studies
- Treatment feasibility studies
- Design and installation of an emergency groundwater recirculation system
- Performance evaluation of the emergency groundwater recirculation system.

The existing emergency groundwater pumping system, which consists of one extraction well and five recharge chambers, was installed in the fall of 1982. The purpose of the system was to provide emergency containment of the contaminated groundwater plume and minimize its migration off-site. A skimmer pump connected to the system has also captured approximately 1,000 gal of the non-aqueous phase liquids which are floating on the groundwater surface. These liquids are being stored on-site in a holding tank prior to shipment off-site for treatment and disposal.
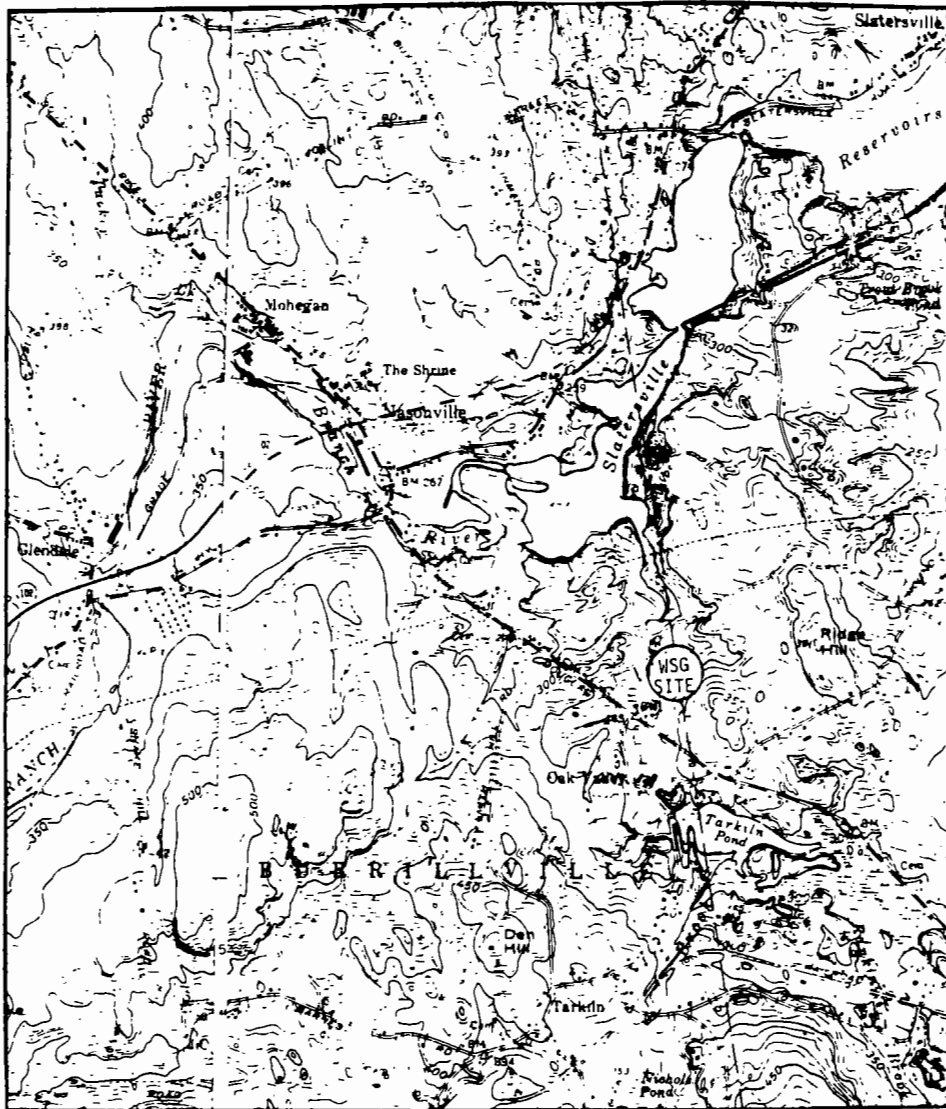
Figure 1
Western Sand and Gravel Site

This current pumping system has been operational for approximately 15 months and has pumped nearly 9,000,000 gal of groundwater for redistribution to the recharge chambers. There have been some periods of pumping interruption and procedures are being implemented to improve the performance of the system. The system has effectively captured the non-aqueous phase liquids floating on the groundwater surface. However, a review of the available downgradient monitoring data before and after installation of the pumping system does not show appreciable change in contaminant levels measured over time.

CONTAMINANT MIGRATION

Samples collected during this program plus additional data collected previously reveal that both groundwater and surface water at WSG are contaminated. These contaminated waters flow in a northerly direction from WSG and discharge to the Slatersville Reservoir (Fig. 2). While the Slatersville Reservoir is not a source of drinking water and is used only for recreational purposes, the Reservoir does overlie the Slatersville Aquifer which has been identified by the U.S. Geological Survey (USGS) as a major groundwater aquifer in Rhode Island. The USGS indicated that induced infiltration from the Slatersville Reservoir would be the principal source of recharge to a well field installed in this aquifer.

An analysis of the horizontal and vertical gradients near the Slatersville Reservoir indicates that approximately 80% of the contaminated groundwater discharges to the Reservoir while 20% recharges the Aquifer. Total contaminant loading to the Reservoir is approximately 3 gal/day of volatile organics assuming a groundwater flow of 9,000 gal/day with a worst case volatile organic content of 410 ppm based upon observations at well GZ-3 (Table 2). The dilution capacity of the Reservoir in the area of the contaminated discharge was estimated at 30 million gallons yielding an effective concentration of 0.1 mg/l of total volatile organics. The concentration of specific chemicals would be appreciably lower. Approximately 0.7 gal/day of volatile organics would flow to the Aquifer which, in turn, discharges to the Reservoir. Given the current and projected recreational use of the Reservoir, there is no acute or chronic public health risk associated with exposure to the toxic substances via ingestion of or dermal contact with contaminated surface water in the Reservoir.

Several residential drinking water wells adjacent to WSG are contaminated with low levels of hazardous chemicals. These wells (Fig. 2) are being monitored by the Rhode Island Department of Health (DOH) as part of their program for evaluating groundwater quality in the area adjacent to WSG. There are currently seven domestic drinking water wells which have shown the presence of

Table 1
Residual On-Site Contamination at WSG

Concentration in Selected Media (ppb)

Chemical	Contaminated Soils Aug. 1982	Non-Aqueous[1] Phase Liquids Dec. 1982	Contaminated Groundwater Nov. 1983 OW-1	E2-3
Methylene chloride*	21,000	140,000	28,400	46,600
1,1-Dichloroethane	3,000	20,000	1,680	540
Trans-1,2-Dichloroethylene*	1,000	15,000	7,660	4,080
Chloroform		120,000	4,000	3,140
1,1,1-Trichloroethane	13,000	4,900,000	19,100	30,000
Trichloroethylene*	35,000	4,100,000	10,300	13,500
Tetrachloroethylene	60,000	3,800,000	1,560	2,400
Chlorobenzene	156,000	25,500,000	17,000	23,300
Benzene*	2,000	400,000	510	830
Toluene	20,000	153,000,000	37,800	231,000
Ethylbenzene	69,000	20,300,000	5,460	7,780
Xylenes	355,000	78,400,000	19,600	39,000
PCB's		73,000		
August 1983				
1,2-Dichlorobenzene	4,900			
Napthalene	2,600	360,000		
Nitrodiphenyl amine	47,000			
Pentachlorophenol	2,300			
Anthracene	2,000	63,000		
Di-Butylphthalate	6,500			
Bis-2-ethyl hexyl phthalate	60,000			
Other Non Priority Pollutants	316,000			

1. Based upon GC and GC/MS analyses. *Suspect Carcinogens.

Table 2
Analysis of Groundwater Samples, Western Sand and Gravel

Concentrations of Various Sampling Sites (µg/l)

Parameter	RW-1	E3-1	E3-2	GZ1-1	GZ1-2	GZ1-3	SS-3	SS-5
Volatile Organic Compounds								
methylene chloride	ND	ND	ND	1	ND	ND	14	ND
1,1-dichloroethylene	2	ND	ND	1	10	14	ND	ND
1,1-dichloroethane	7	ND	1340	ND	184	226	6	23.
trans-1,2-dichloroethylene	20	ND	ND	3	398	202	98	23
chloroform	ND	ND	ND	ND	ND	51	2	2
1,2-dichloroethane	ND	ND	ND	ND	2	ND	1	2
1,1,1-trichloroethane	ND	ND	ND	ND	12	66	50	3
carbontetrachloride	ND	ND	ND	ND	ND	ND	ND	ND
bromodichloromethane	ND	ND	ND	ND	ND	ND	2	1
1,2-dichloropropane	ND	ND	ND	ND	ND	ND	ND	ND
trans-1,3-dichloropropene	ND	ND	ND	ND	ND	ND	ND	ND
trichloroethylene	ND	ND	ND	ND	ND	ND	20	ND
1,1,2-trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND
cis-1,3-dichloropropene	ND	ND	ND	ND	ND	ND	ND	ND
dibromochloromethane	ND	ND	ND	ND	ND	ND	ND	ND
bromoform	ND	ND	ND	ND	ND	ND	ND	ND
tetrachloroethylane	ND	ND	ND	ND	ND	ND	1	ND
1,1,2,2-tetrachloroethane	ND	ND	ND	ND	ND	ND	ND	ND
chlorobenzene	ND	ND	1260	ND	23	64	28	1
benzene	ND	ND	19	ND	10	38	ND	ND
toluene	ND	ND	2800	ND	87	440	184	45
ethylbenzene	ND	ND	140	ND	32	190	22	29
xylene	ND	ND	790	ND	120	720	103	133
Detection Limit	1 µg/l	1 µg/l	1 µg/l	1 µg/l	1 µg/l	10 µg/l		

Note: Results in µg/l ND = none detected

Table 2 Continued

Parameter	GZ4-1	GZ4-2	GZ4-3	GZ5-1	GZ5-2	GZ5-3
Volatile Organic Compounds						
methylene chloride	ND	ND	ND	ND	ND	3
1,1-dichloroethylene	ND	ND	16	ND	ND	2
1,1-dichloroethane	ND	3	194	ND	ND	14
trans-1,2-dichloroethylene	ND	55	410	ND	ND	28
chloroform	ND	ND	4	ND	ND	ND
1,2-dichloroethane	ND	ND	4	ND	ND	ND
1,1,1-trichloroethane	ND	ND	24	ND	ND	4
carbontetrachloride	ND	ND	3	ND	ND	ND
bromodichloromethane	ND	ND	ND	ND	ND	ND
1,2-dichloropropene	ND	ND	ND	ND	ND	ND
trans-1,2-dichloropropene	ND	ND	ND	ND	ND	ND
trichloroethylene	ND	1	10	ND	ND	ND
1,1,2-trichloroethane	ND	ND	ND	ND	ND	ND
cis-1,3-dichloropropene	ND	ND	ND	ND	ND	ND
dibromochloromethane	ND	ND	2	ND	ND	ND
bromoform	ND	ND	ND	ND	ND	1
tetrachloroethylene	ND	ND	5	ND	ND	ND
1,1,2,2-tetrachloroethane	ND	ND	ND	ND	ND	ND
chlorobenzene	ND	ND	13	ND	ND	ND
benzene	ND	ND	35	ND	ND	3
toluene	ND	4	43	5	ND	5
ethylbenzene	ND	ND	34	ND	ND	4
xylene	ND	ND	170	ND	ND	24
Detection Limit	1 µg/l	1 µg/l	1 µg/l	1 µg/l	1 µg/l	1 µg/l

1. EPA Ambient Water Quality Criteria for Human Health.   *Suspect Human Carcinogens 10⁻⁶ Cancer Risk.
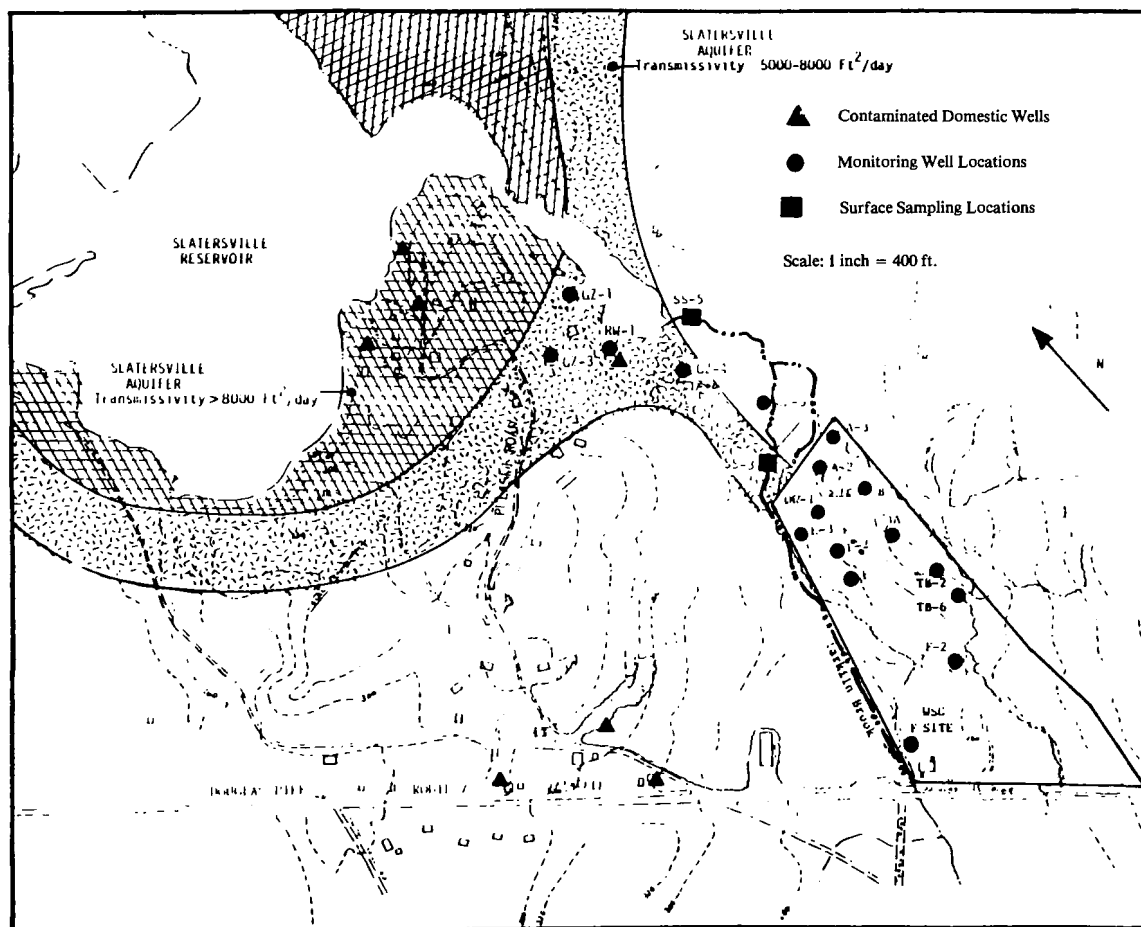
Figure 2
Hydrogeologic Setting at WSG
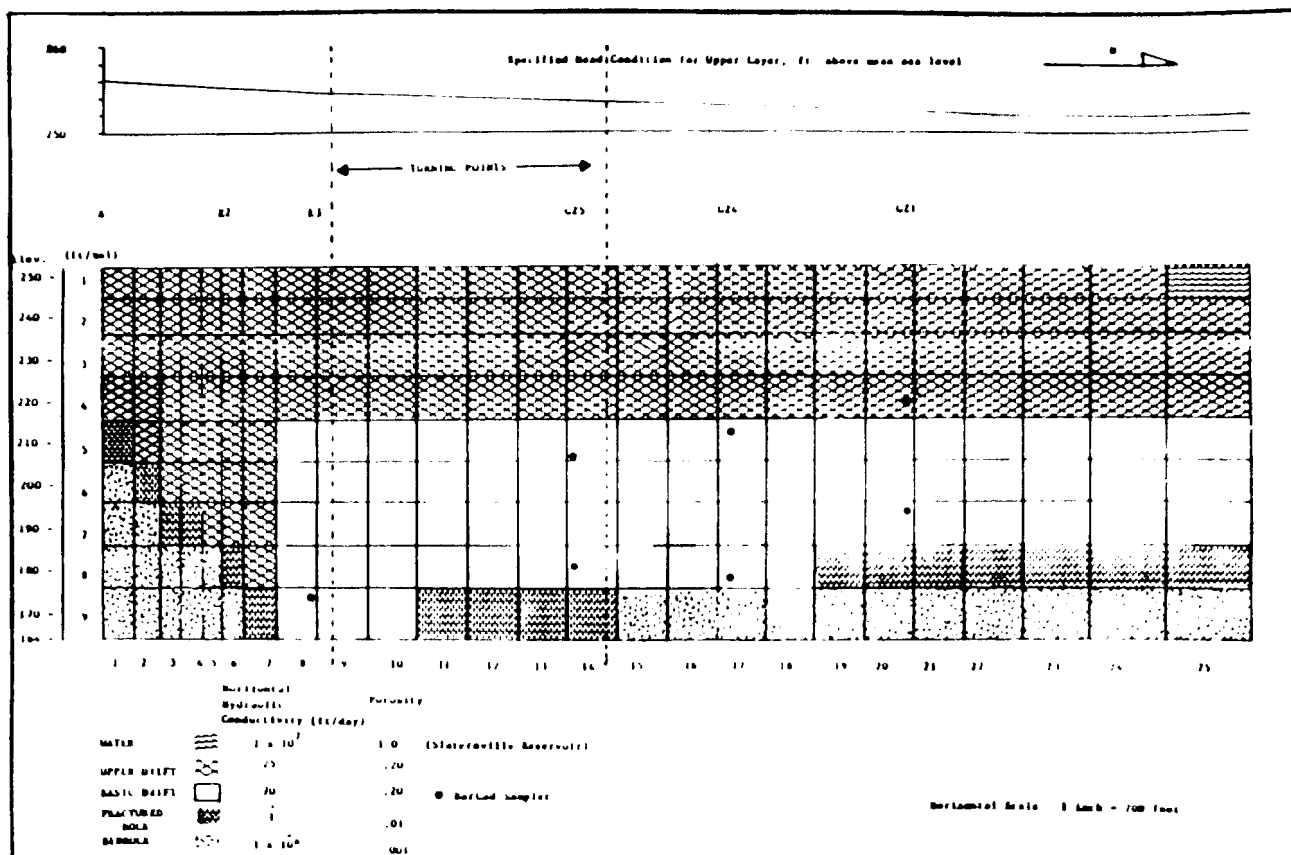
Figure 3
Physical Conditions at WSG

organic chemical contamination at least once in their sampling history. Four of these wells have shown contamination each time they were sampled over the past 30 months and three are located within the Slatersville Aquifer (Fig. 2).

A volatile organic priority pollutant analysis of groundwater samples collected at WSG and adjacent areas is found in Table 2. Table 3 shows the USEPA Quality Criteria for Human Health and Aquatic Toxicity and the designation of those contaminants which are suspect human carcinogens. Several of the wells listed in Table 2 are multi-level, and these provide a profile on water quality at different depths below the ground surface. For example, samples designated GZ1-1, GZ1-2 and GZ1-3 are taken from the same well location. GZ1-1 represents a sample collected 7.5 ft below the ground surface, GZ1-2 indicates a sample taken 45 ft below the ground surface and GZ1-3 was 75 ft below the surface. Similar multi-level sampling configurations exist in wells E3, GZ4 and GZ5. A review of the data indicates that contaminant concentrations are highest at the deepest location within a given well. For example, locations E3-2, GZ1-3, GZ4-3 and GZ5-3, which are the deepest sampling points in each well, all show levels of contamination higher than at shallower sampling locations in the same wells. Wells GZ4 and GZ5 show upward groundwater gradients at their deepest sampling locations. No gradient data are available for wells E3 and GZ1.

The individual groundwater sampling locations shown on Figure 2 indicate the northerly movement of contamination from WSG toward the Slatersville Reservoir. Residential sampling well RW-1 in Table 2 has the highest level of contamination among the domestic wells. This well is no longer used for drinking water, and the resident has chosen to use bottled water. Also, surface sampling locations SS-3 and SS-5 represent samples collected in the Tarkiln Brook. Total volatile organics measured at SS-3 and SS-5 were approximately 530 and 260 µg/l, respectively. The concentration for some chemicals in the stream samples exceeded USEPA water quality criteria for drinking water but did not pose an acute or chronic toxicity hazard for aquatic species.

INITIAL ASSESSMENT OF PUBLIC HEALTH RISK

The estimates for public health risk are based upon the results from the monitoring of groundwater and surface water contamination at WSG. Additional considerations relate to the quantities of hazardous wastes which remain at the site and the possibility for their release to groundwater and surface water.

The public health risk assessment is based upon the contaminant concentration levels measured in well GZ1 which is the monitoring well closest to impacted residential wells. This estimate of risk presented in Table 4 is based upon USEPA Water Quality Criteria for Human Health. The total risk estimate, assuming that carcinogenic risks are additive, is equivalent to 310×10^{-6} based upon a lifetime ingestion of drinking water containing the chemicals at concentrations shown in Table 4.

ASSESSMENT OF REMEDIAL ALTERNATIVES

The data presented in Table 4 indicate that the chronic ingestion of contaminated groundwater poses a lifetime cancer risk of 310×10^{-6} based upon USEPA water quality criteria. This cancer risk could be higher if 1,1 dichloroethane and trans-1,2-dichloroethylene are shown upon further study to be carcinogenic. The analysis proceeds to evaluate the relative effectiveness of remedial alternatives with respect to reducing contaminant migration from the site.

A two-dimensional cross-section flow and solute transport model was used to examine the effectiveness of the various remedial alternatives. The physical representation of the site, including the geometry and physical (hydrogeological) conditions, is shown on Figure 3. This grid system for the specific cross section was selected to generally coincide with the groundwater flow line which parallels flow in the Tarkiln Brook. The water table elevation for the upper laver was specified initially and held constant during the period of simulation. The bottom and lateral edges of the grid were defined to be no-flow boundaries. For the left edge of the grid, this repre-

Table 3
Selected Water Quality Criteria Information

Compound	USEPA Ambient Water Quality Criteria for Human Health[a] (μg/L)	Calculated Drinking Water Criteria[b] (μg/L)	USEPA Ambient Water Quality Criteria for Freshwater Aquatic Organisms (μg/L)	Biocon-centration Factor	MCL's[c] (μg/L)	USEPA Health Advisory (μg/L)
methylene chloride	0.19[dk]	0.19[dk]	11,000[ck] (bluegill)	0.91	---	1 day 13,000 / 10 day 1,300 / long term 150
1,1 dichloroethylene	0.03[d]	0.03[d]	11,600[e] (Daphnia magna)	5.6	---	1 day 1,000 / long term 70
1,1-dichloroethane	Insufficient data	----	Insufficient data	---	---	not released
trans-1,2-dichloroethylene	Insufficient data	----	11,600[e] (Daphnia magna)	---	---	1 day 2,700 / 10 day 270
chloroform	0.19[d]	0.19[d]	1,240[f] (rainbow trout embryos)	3.8	100[j]	none
1,2-dichloroethane	0.94[d]	0.94[d]	20,000[f] (fathead minnow)	1.2	10[hi]	not released
1,1,1-trichloroethane	18,400	18,700	18,000[e]	5.6	1000[i]	long term 1000
trichloroethylene	2.7[d]	2.8[d]	45,000[c] (Daphnia pulex)	10.6	50[i]	1 day 2,000 / 10 day 200 / long term 75
tetrachloroethylene	0.8[d]	0.9[d]	840[f] (fathead minnow)	30.6	50[hi]	1 day 2,300 / 10 day 175 / long term 20
chlorobenzene	20[g]	20[g]	250[e] (bluegill)	10.3	---	not released
benzene	0.66[d]	0.67[d]	5,300[e] (rainbow trout)	5.2	---	1 day 230 / long term 70
toluene	14,300	14,800	17,500[e]	10.7	---	1 day 21,500 / 10 day 2,200 / long term 340
ethyl benzene	1,400	1,600	32,000[e] (bluegill)	37.5	---	none
xylene	none	----	none	---	---	1 day 12,000 / 10 day 1,400 / long term 620

a. Considers exposure via drinking water and fish which may bioaccumulate the compound
b. A recalculation of the water quality criteria to consider drinking water only
c. Maximum contaminant levels for drinking water
d. For suspected carcinogens at 10^{-6} risk
e. Lowest level at which acute toxicity has been observed for freshwater aquatic life
f. Lowest level at which chronic toxicity has been observed for freshwater aquatic life
g. Based on organoleptic data, based on health effects data the criteria would be 488 μg/L
h. For suspected carcinogens at 10^{-5} risk
i. Proposed recommended maximum contaminant levels
j. MCL for total trihalomethanes
k. For total halomethanes

sents the contact between glacial deposits and bedrock and assumes very little or no lateral groundwater flow across this contact. For the right edge of the grid, this boundary condition represents groundwater discharge at the edge of the Slatersville Reservoir and no lateral groundwater flow beneath the Reservoir. The bottom no-flow boundary represents the relatively unfractured crystalline bedrock.

Two basic groundwater simulations were designed in order to provide a framework for bounding the various remedial actions. The initial simulation addressed a no-action alternative and evaluated both the maximum downgradient concentrations and their time of arrival at receptor locations. The second simulation estimated the time required for natural groundwater flow to flush contaminated groundwater from the system assuming that the contaminant source was removed or encapsulated. The details of the simulation are discussed below. Two simulations were made assuming a constant source strength of 10,000 μg/l for a mobile species (those which migrate at a rate comparable to groundwater velocity) and 100,000 μg/l for an immobile species (those whose migration rates are retarded based upon their physical and chemical properties). These individual loading rates are comparable to those expected under a no-action alternative at the site. Simulations were made for a twenty-year period and the results are summarized as follows. For the mobile species, measurable concentrations (>1 μg/l) would be expected to reach grid block 20 (Fig. 3) within 5 years and equilibrium concentrations of approximately 2,700 μg/l (or 27% of the source strength) could be expected within 15 years for no-action alternative. The calculated contamination distributions at the end of 10 and 15 years are shown in Figure 4.

The contaminant plume for the retarded species (Fig. 5) is much less extensive at the end of 15 years. However, it still effects a sig-

nificant area under the no-action alternative. It is important to recognize that these models are only approximate and that the actual extent of plume migration at WSG is probably represented by a situation intermediate between the predictions of the two models.

A second simulation was made to estimate the natural restoration capabilities of the groundwater flow system. An initial contaminant distribution throughout the aquifer system was specified. The specified distribution was similar to the 10-year calculated distribution for the mobile chemical species of the previous simulations. The source term concentration was defined to be zero, which represents either complete encapsulation or removal of the contaminant source.

The purpose of the simulation was to estimate the minimum time the aquifer would remain contaminated after on-site remedial action. The model results indicate that five year contamination levels immediately below the site would be below detection (<1 μg/l) and the highest concentrations (approximately 3,000 μg/l) would be in the vicinity of GZ-5. After 10 years, the highest concentration levels would be approximately 200 μg/l in the vicinity of GZ-1. It would take approximately 15 years for the contamination levels in the vicinity of GZ-1 to drop below 1,000 μg/l. Figure 6 illustrates the change in position of the 1,000 μg/l iso-contour at five-year intervals. The results of these analyses indicate that with natural cleansing, groundwater in the vicinity of GZ-1 remains contaminated (at levels greater than 1,000 μg/l) for at least 15 years and that between 15 and 30 years are required for levels to decrease significantly below 1,000 μg/l.

The results from the preliminary model runs were used to establish the initial conditions for the evaluation of remedial alternatives. Initial conditions for the hydrogeologic system relate to the
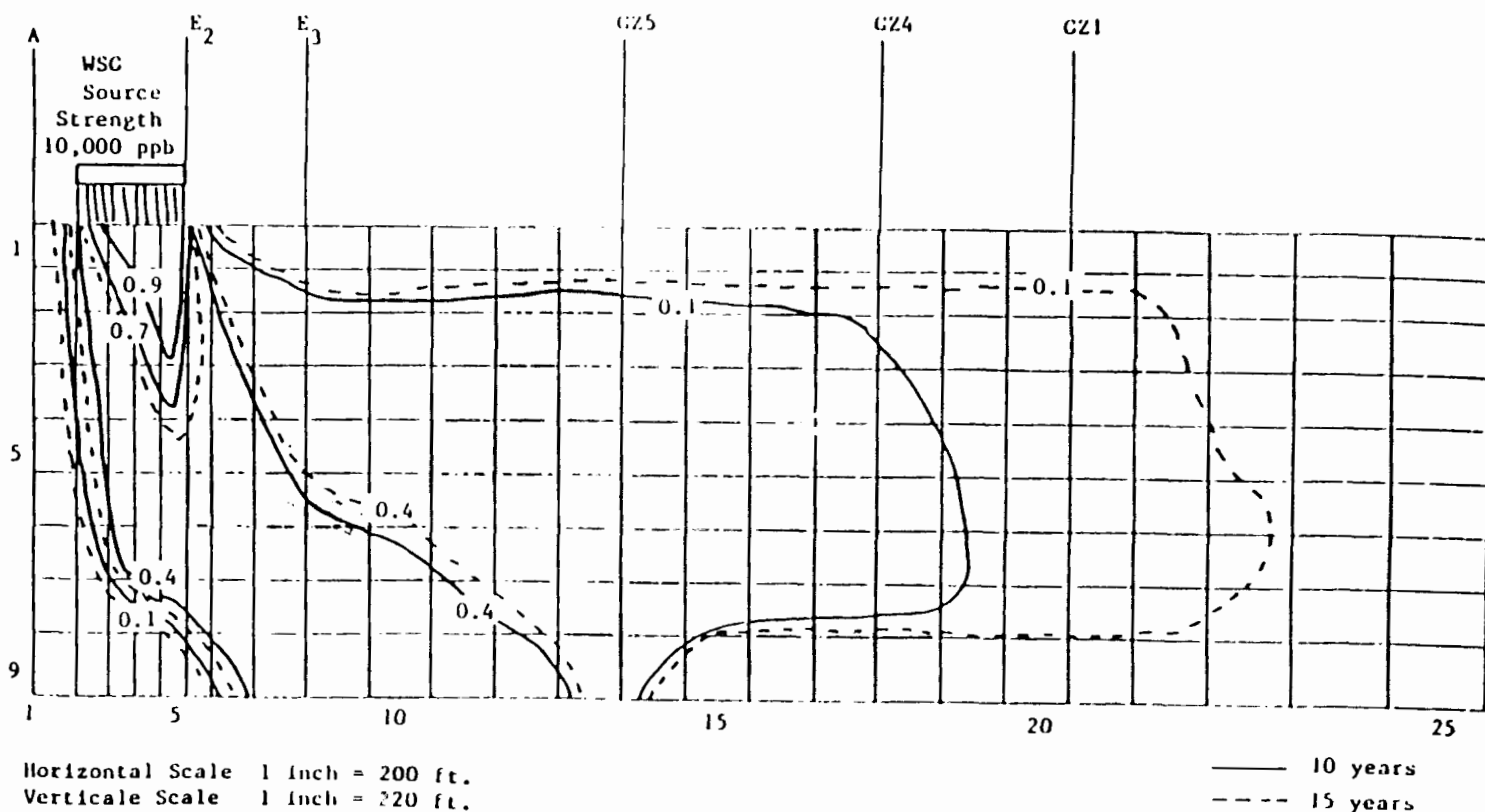
Figure 4

Fractional Concentration of Mobile Species after 10 and 15 Years of Source Loading at 10,000 ppb. X and Y Axes Correspond to Figure 3.
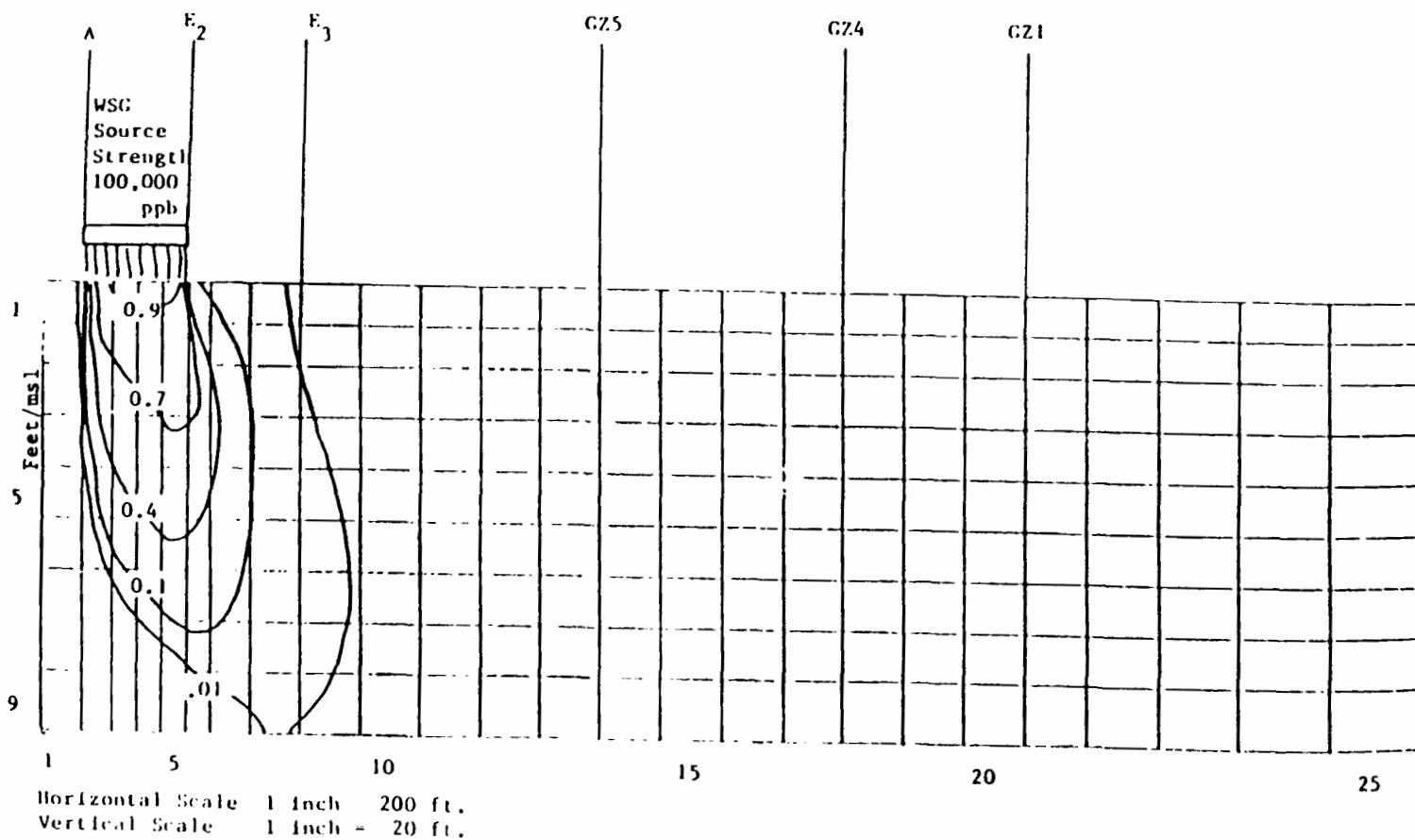

Figure 5

Fractional Concentration of Retarded Species after 15 Years of Loading at 100,000 ppb. X and Y Axes Correspond to Figure 3.

Table 4
Baseline Level of Health Risk

	Well Concentrations (µg/l) 1982		1983		Average Concentration (µg/L)	USEPA Water Quality Criteria for Health (µg/L)	Risk From Lifeti Exposure
	GZ1-2	GZ1-3	GZ1-2	GZ1-3			
1,1-dichloroethane	37	131	184	226	144	insufficient data	
1,1-dichloroethylene	ND	2	10	14	6	$(.03)^A$	200×10^{-6}
trans-1,2-dichloroethylene	110	128	398	202	210	insufficient data	
chloroform	ND	ND	ND	51	12	$(.19)^A$	60×10^{-6}
1,2-dichloroethane	3	14	2		5	$(.94)^A$	5×10^{-6}
1,1,1-trichloroethane	14	31	12	66	31	18,400	negligible
chlorobenzene	2	12	23	64	25	20^B	negligible
benzene	19	52	10	38	30	$(.66)^A$	45×10^{-6}
toluene	25	236	87	440	197	14,300	negligible
ethylbenzene	31	252	32	190	126	1,400	negligible
xylenes	153	1000	120	720	498	620^C	negligible
TOTAL	394	1856	868	1946	1284		310×10^{-6}

A. 10^{-6} cancer risk.
B. Based on organoleptic data, 488 for health.
C. Long-term health advisory.
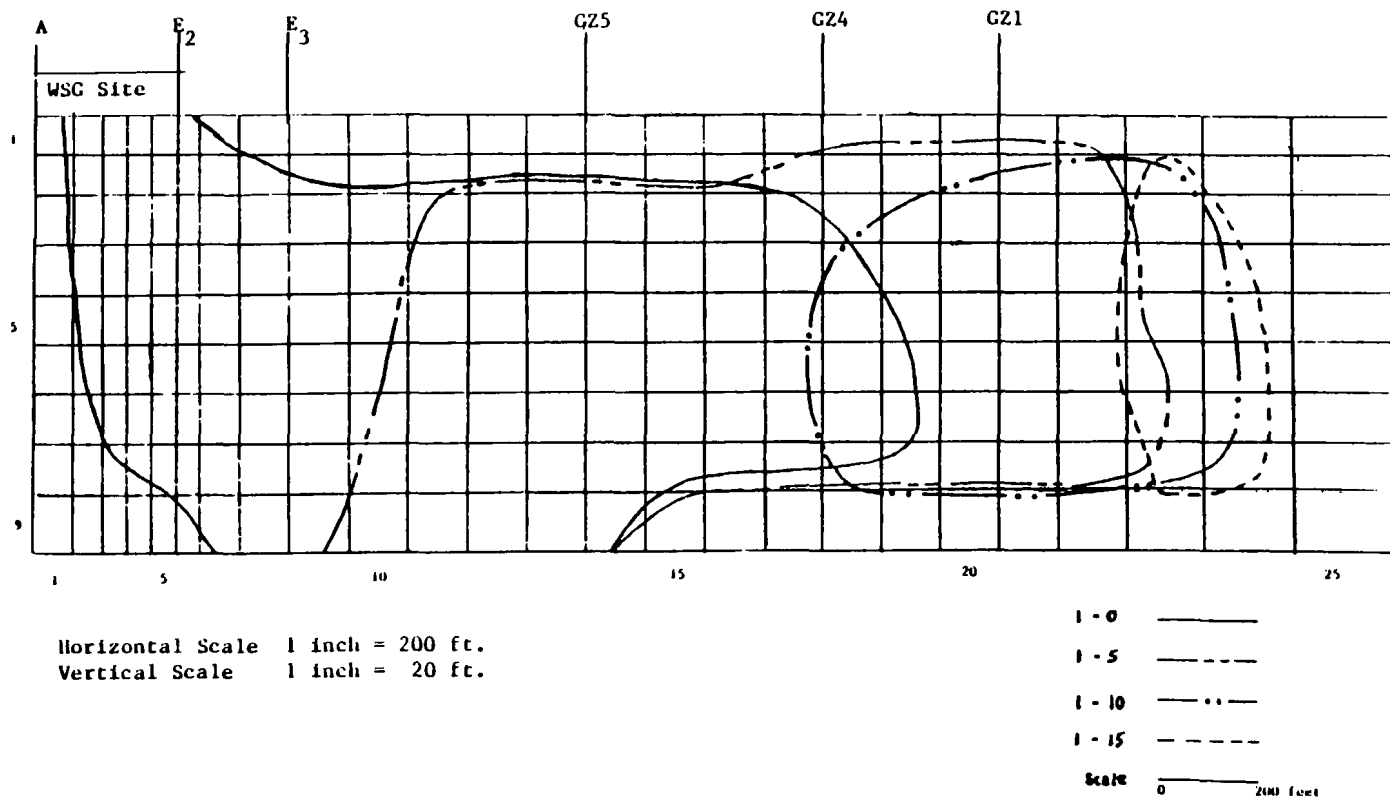
Figure 6
Position of Contaminant Plume (Concentration 1000 ppb) at 0, 5, 10 and 15 Years. X and Y Axis Refer to Figure 3.
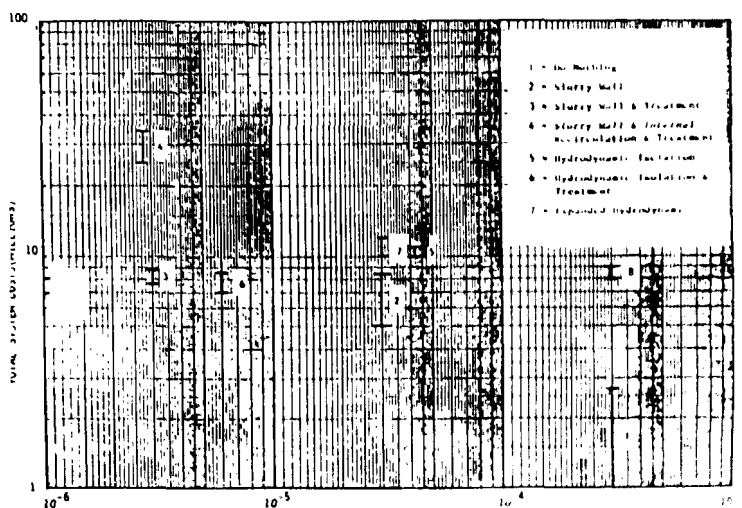
Figure 7
Range of Total System Costs Versus Level of Risk

reduction in source strength that is anticipated following the implementation of the various remedial alternative considered for the WSG site.

The initial conditions regarding flow rate at the site and contaminant loading rate for the remedial alternatives considered in this study are shown in Table 5. Simulation runs were conducted for each remedial alternative, and final steady-state conditions were measured to evaluate the effectiveness of the remedial alternative. Final steady-state contaminant levels under each remedial alternative were then compared with the results under a no-action alternative. The reduction in the level of contamination was then accepted as a measure of the system efficiency.

The removal efficiency was then employed to evaluate the level of risk reduction for each remedial alternative. Risk reduction is based upon the removal of suspect human carcinogens from the groundwater and a concomitant reduction in the level of chronic ingestion. The level of risk associated with each remedial alternative is presented in Table 5. Analysis shows that the greatest level of risk reduction is achieved through the implementation of the slurry wall with treatment and recirculation of the pumped

	RELIABILITY	IMPLEMENTABILITY	OPERATION AND MAINTENANCE REQUIREMENTS	ENVIRONMENTAL AFFECT	SAFETY REQUIREMENTS	COST	TIME FOR IMPLEMENTATION	FEASIBILITY	ABILITY TO RESTORE GROUNDWATER QUAL	IMPACT ON PROPERTY VALUES	PUBLIC ACCEPTANCE	POTENTIAL LITIGATION	LEVEL OF PERCEIVED RISK	ON-SITE OFF-SITE IMPACTS	PROXIMITY TO RESIDENTS	TOTAL
Do Nothing	10	10	10	1	1	1	10	10	1	1	1	1	1	1	10	69
Slurry Wall	10	10	10	5	10	10	10	10	5	10	10	10	10	10	10	140
Slurry Wall & Treatment	10	5	5	10	10	5	5	5	10	10	10	10	10	10	10	125
Slurry Wall & Internal Recirculation & Treatment	5	5	5	10	10	5	5	5	10	10	10	10	10	10	10	120
Hydrodnamic Isola	5	5	5	10	10	10	10	10	5	10	10	10	10	10	10	130
Hydrodynamic Isolation & Treatment	5	5	5	10	10	5	5	5	10	10	10	10	10	10	10	120
Expnded Hydrodynm	5	5	5	10	10	5	5	5	5	10	10	10	10	10	10	115
Buy-Out	10	1	10	5	10	5	1	10	1	1	10	10	5	5	5	69

Figure 8
Second Level Analysis of Remedial Options

Table 5
Risk Levels Associated with Remedial Options

Remedial Option	Flow Rate at Site (gal/day)	Contaminant Loading (μg/l)	Removal Efficiency (%)	Risk Level x 10⁻⁶
Do-Nothing	9,000	10,000	0	310
Slurry Wall	900	1,000	90	31
Slurry Wall & & Treatment	900	30	99	3
Slurry Wall & Internal Recirculation & Treatment	300	15	99+	3
Hydrodynamic Isolation	1,300	1,440	86	43
Hydrodynamic Isolation & Treatment	1,300	144	98	6
Expanded Hydrodynamic	900	1,000	90	31

effluent. The slurry wall with treatment and no recirculation and the groundwater pumping system also demonstrated relatively high removal efficiencies.

IDENTIFICATION OF COST EFFECTIVE REMEDIAL ALTERNATIVES

The levels of risk reduction information in Table 5 was combined with net present value for total system costs to assess the relative effectiveness of the remedial alternatives. This information for the eight options considered in this program is shown in Figure 7.

The information shown in Figure 7 provides a basis for establishing a feasible domain regarding the level of public health risk and costs for the remedial alternatives.

A variety of scientific literature suggests that humans are generally willing to accept risks to health in the range of 10^{-5} to 10^{-6}. Given this criteria, it appears that remedial Alternatives 1, 2, 5, 7 and 8 should be excluded from further considerations. A second major consideration regarding the remedial alternatives relates to the net present value of capital and operating costs for the life of the system. The total system costs as presented in Figure 7 consist of a range which reflects a measure of uncertainty. For example, the total system costs for Alternative 3, the slurry wall and treatment system ranged from $7,800,000-$8,900,000. This is typical of the cost variations which can be anticipated in this type of analysis. Based upon the cost analysis, it appears that systems 3 and 6 represent the most cost-effective remedial alternatives with respect to risk reduction.

Public health risk and system costs are two parameters which can be employed to evaluate remedial alternatives. However, there are a variety of other screening criteria which should be employed to select viable remedial systems. These criteria, shown in Figure 8, were ranked from 1-10 for each of the remedial systems considered in this analysis. Each of the secondary screening criteria is unweighted and the total score for each system is shown in the right column. The results from the secondary screening indicate that remedial systems 3 and 6 score near the top with respect to overall ranking of the remedial alternatives.

In conclusion, the application of a quantitative risk assessment in conjunction with considerations for cost and secondary screening criteria provides a basis for evaluating remedial alternatives at hazardous waste disposal sites. This methodology provides a basis for explicitly considering public health risk in the evaluation of remedial alternatives.

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APPROACHES TO COMPUTER RISK ANALYSIS AT UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

In this paper, the authors outline an approach to the assessment of health risks at uncontrolled hazardous waste sites, and they discuss several applications of computers in the risk analysis process. An integrated risk analysis model currently being developed for hazardous waste facilities is then described to illustrate some of the principles of computerized risk assessment. Finally, some of the advantages and disadvantages of using computers in risk anslysis are summarized. Before proceeding, however, three basic questions should be addressed.

What is Risk Analysis?

Risk analysis is defined here, in the context of hazardous waste sites, as "the systematic scientific characterization of the probabilities and types of adverse effects that may result from chemical releases at the site." The authors focus on risks of chronic human health effects, although risk analysis can also be used to evaluate ecological and environmental effects, health effects of acute exposures or other types of adverse consequences. To the degree possible, risk analysis is independent of political, legal and economic considerations that must be factored into decision-making. This distinction between the scientific evaluation of risk and the management of risk is consistent with the recent recommendation of the National Academy of Sciences (NAS)[1] and with current USEPA policy.[2] The approaches and models described in this paper are risk analysis tools which must be integrated with other sources of information in site decision-making.

Why Use Risk Analysis?

There are a number of reasons to use risk analysis at hazardous waste sites. In fact, rational decisions about remedial actions at most sites cannot be made in the absence of health risk analysis, although the form and extent of the analysis may vary widely, even to the point of being unrecognizable as risk analysis. The authors would argue that even the use of existing environmental criteria or standards to guide actions at a site is a form of combined risk analysis/risk management. Thus, the question is not so much whether to use risk analysis in remedial site management, but what form the analysis should take and how comprehensive it should be.

Specific applications of risk analysis at individual uncontrolled hazardous waste sites include the following:

•Evaluation and comparison of site remedial action alternatives on a health basis
•Final design specification for a selected remedial alternative
•Characterization of baseline site risks (i.e., risks in the absence of remedial action)

•Characterization of residual site risks (i.e., risks existing following the remedial action)
•Evaluation of health benefits, in terms of risk reduction, resulting from a remedial action

Thus, risk analysis can play a role in demonstrating the need for action at a site, in selecting and designing a remedial action for the site and in evaluating the effectiveness of the action. Risk analysis can also be applied to questions concerning multiple sites, such as site ranking, establishment of cleanup priorities and evaluation of overall remedial program benefits.

What are the Drawbacks to Risk Analysis?

If systematic risk analysis is so useful at uncontrolled hazardous waste sites, then why has it not been more widely used? The authors believe that there are three primary reasons for its lack of utilization:

•The unavoidable analytical uncertainties involved in environmental risk analysis
•The substantial site-specific data requirements for a defensible analysis
•The perception that risk analysis will slow the remedial process

The authors do not dismiss these concerns, and in fact do point them out as a cautionary note. Nevertheless, the authors believe these concerns to be counterbalanced by the potential benefits of risk analysis at a site.

Uncertainty is perhaps the foremost certainty in environmental risk analysis, and site decision-makers seeking precise risk estimates will be disappointed. However, by estimating the reasonable ranges of risk estimates and by using techniques such as sensitivity an analysis and worst-case assessment, one can produce useful risk analyses despite the uncertainties. The data needs for risk analysis are considerable, but these can be met during the site characterization process at most sites. For this to happen, the risk analysts must be involved in planning and monitoring site characterization activities. As for the perception of slowing site remedial progress, the authors do not think this will be significant if risk analysis is integrated into the overall remedial process. It can almost be guaranteed, however, that a risk analysis tacked on late in the remedial process will prove unsatisfactory and will slow site progress.

In the remainder of this paper, the authors present a general risk analysis approach for hazardous waste sites, describe various uses for computers in the process, present an example of an integrated risk analysis model and summarize the advantages and disadvantages of risk modeling using computers.
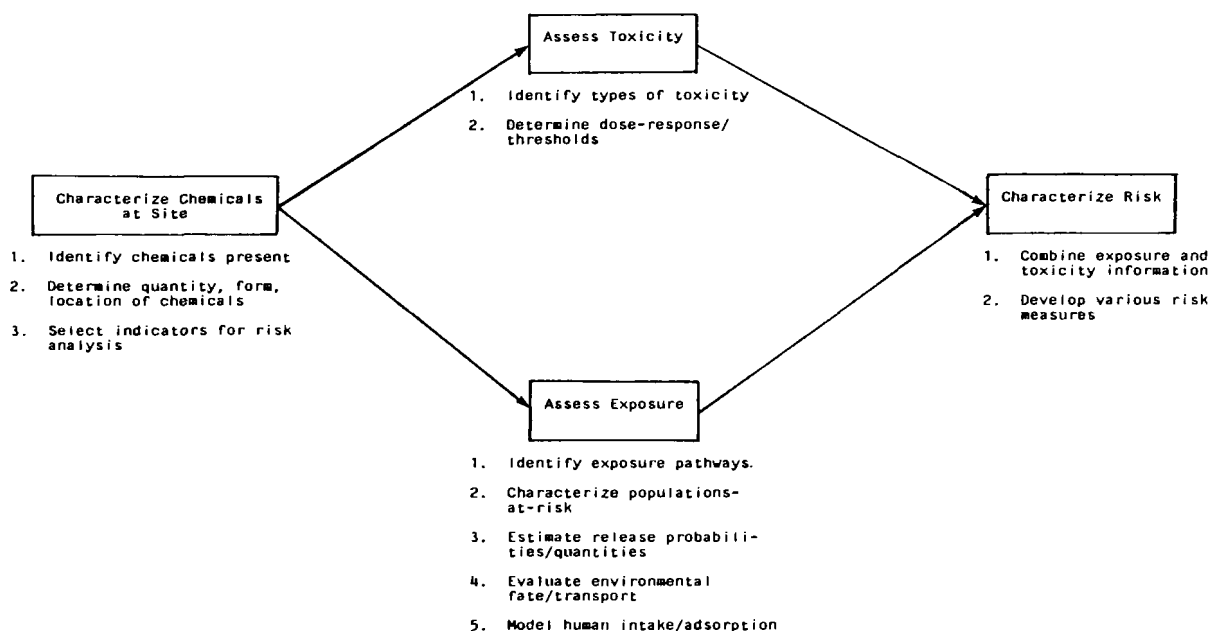
Figure 1
Risk Analysis Approach for Hazardous Waste Sites

GENERAL RISK ANALYSIS APPROACH

The approach described for risk analysis at uncontrolled hazardous waste sites is adapted from traditional risk assessment methods used for pesticides, occupational agents, food additives and drugs. However, it takes into account some of the characteristics of waste sites that make risk analysis more difficult: multiple chemicals; multiple release sources and exposure pathways; multiple exposed populations; and separation of release sources and receptors in time and space. The approach is consistent with the chemical risk assessment principles outlined recently by the NAS.[1] The approach is only briefly described here, as the focus of this paper is computer applications.

The risk analysis approach consists of four steps that roughly parallel the steps outlined by NAS. The first step is characterization of the toxic chemicals present at the waste site. The next two steps are chemical toxicity assessment and exposure assessment. Finally, the exposure and toxicity information is integrated to characterize the risks. Figure 1 is a flow chart showing the overall risk analysis approach.

Characterize Chemicals

The first step in risk analysis is to characterize the toxic chemicals present at the waste site. In addition to simply identifying the chemicals, their locations at the site and the quantities present must be estimated. This step is based on chemical analysis data for the site and in some cases can be supplemented by site disposal records. Because many waste sites may contain more than 100 toxic chemicals, indicator chemicals should be selected for the risk analysis. It is impractical and unnecessary to include a large number of chemicals in the risk analysis; a few indicators of the risk are selected based on their toxicity, environmental mobility, persistence and the quantity present.

Assess Toxicity

In this step, the inherent toxicity of each indicator chemical is assessed. The types of toxic effects, the levels at which these effects occur and the dose-response relationships must be determined for each chemical. The precise form of the quantitative data required will depend on the dose-response model being used. Because the assessment of inherent toxicity does not require site-specific data, this step can be done prior to the actual risk analysis.

Usually, this assessment is based on human epidemiological studies or experimental animal studies. In practice, many of the chemicals encountered will have toxicity assessments available and will not need to be reassessed. For example, the USEPA's Carcinogen Assessment Group has derived dose-response data for many suspected carcinogens,[3] and the USEPA and the FDA have determined acceptable daily intake (ADI) values for many noncarcinogens.[4] If further assessment is required, however, the services of an experienced toxicologist will be needed to complete this step.

Table 1
Hypothetical Exposure Pathway Matrix

Release Source	Exposure Pathway		Remedial Alternative			
	Release/ Transport Medium	Point of Exposure	1	2	3	4
Site leachate	Groundwater	Public drinking water	x	x		x
Site leachate	Groundwater	Private drinking water	x	x	x	x
Abatement plant effluent	Surface water	Downstream swimming			x	x
WTP Volatilization	Air	Nearest residence	x	x		x
Wellhead treatment volatilization	Air	Nearest residence			x	
Abatement plant volatilization	Air	Nearest residence			x	x

Assess Exposures

This is typically the most complex and time-consuming part of the analysis. Exposures of people affected by the waste site must be quantified for all indicator chemicals. Although environmental and human monitoring data can be extremely useful if available, this step almost always requires modeling of chemical releases from the site and transport to the exposure point. Some type of modeling, which can vary from a series of logical assumptions to a full multimedia simulation of the waste site, is necessary whenever exposures must be estimated into the future.

The exposure assessment can be divided into several activities. First, an exposure pathways analysis must be done to identify: (1) the significant sources of potential chemical release to the environ-

ment, (2) the release and transport media (e.g., air, groundwater) for each source, (3) points of potential human exposure and (4) the exposure medium and exposure route. A hypothetical exposure pathway summary for an uncontrolled hazardous waste site is shown in Table 1. Each complete exposure pathway that is judged significant represents a chain of events for which chemical exposures must be quantified. The population-at-risk for each exposure point (or area) also should be quantified.

For each significant exposure pathway, chemical release from the source must be projected, preferably in the form of release profiles for individual chemicals. A release probability must also be estimated for stochastic sources of release. Typically, the estimation of chemical releases is one of the more problematic steps in risk analysis for hazardous waste sites. Following the projection of release profiles for a specific source, the fate and transport of chemicals between the source and any exposure points must be evaluated. This analysis can be done using simple dilution, dispersion and degradation equations or complex computer models. The objective is to estimate the chemical concentration in the exposure medium at the exposure point. Finally, human intake of or contact with the exposure medium must be modeled to allow projection of the chemical dose.

Characterize Risk

This step is the integration of the information developed in the previous steps of the risk analysis. The risks of various adverse effects are calculated for each indicator chemical and each appropriate exposure pathway by combining the projected doses with the dose-response data. Various risk measures can be developed, including maximum and average individual risk and population risk. The exact procedure for combining this information will be prescribed by the dose-response model selected and may vary for different chemicals. For example, a linear non-threshold model could be used to evaluate carcinogens, and non-carcinogens could be assessed based on a threshold response. Because of the large amount of risk information generated, it may be desirable to aggregate some risk estimates at this point. For example, risks for pathways affecting the same population could possibly be aggregated, as could risks from all carcinogens.

APPLICATIONS FOR COMPUTERS IN RISK ANALYSIS

Given a risk analysis approach such as that described in the previous section or a similar quantitative approach, there are two ways to proceed. All the calculations and data management can be done by hand or computers can be used to make the analysis easier. For sites at which only a qualitative or simple quantitative assessment is required, the use of computers would be unnecessary. However, for waste sites having many chemicals and several exposure pathways, use of computers can both enhance and facilitate the risk analysis.

Computers can facilitate a risk analysis in many ways. Perhaps most significantly, fully computerized risk models allow a more thorough treatment of the unavoidable uncertainty in any risk analysis. Using a sensitivity or bounding analysis, the reasonable range of risks for a site can be estimated. Computers also have applications in the individual components of the risk analysis, especially fate and transport modeling. Available computer models account for more complex transport processes and use more site-specific data than would be possible using desk-top calculations. The computer models provide more realistic predictions of environmental concentrations. A third significant way that computers can assist a risk analysis is in data management. The large amounts of input data needed to conduct a site risk assessment can be organized in computer data bases. The intermediate and output data produced during the analysis can be tracked by computer, and statistical and graphics packages can be used to produce additional outputs.

Another, more limited, application of computers in risk analysis is data gathering through telecommunication with centralized data bases, especially data bases of chemical properties. Examples of useful on-line data bases are the Toxicology Data Bank (TDB) and the Registry of Toxic Effects of Chemical Substances (RTECS), both maintained by the National Library of Medicine.

Brief descriptions of two computer applications in risk analysis—data management by personal computer (PC) and use of computerized transport models—are given below.

Data Management by PC

PC spreadsheet and data base management packages can be used to manage the data generated during a site risk analysis. Obviously, the risk analysis approach outlined in the second section can generate large amounts of data for even a moderately complex site. Use of a PC to record, organize and store the data can facilitate the analysis. For example, suppose that a site risk analysis was being done for ten chemicals, six exposure pathways and four remedial alternatives to estimate chronic and subchronic risks. In this hypothetical analysis, there could be as many as 480 (10 × 6 × 4 × 2) separate risk pathways to be quantified. Maintaining these data on a PC would greatly assist the analysis. Examples of PC data tables, created for a hypothetical risk analysis using the Lotus 1-2-3 spreadsheet package, are given in Figures 2 and 3. The table in Figure 2 contains chemical concentration estimates for various population exposure points. The table in Figure 3 gives dose estimates for the same chemicals and exposure points, with the algebraic conversion done by the PC. Given the dose-response factor for a chemical, risk values also can be calculated and aggregated on the PC.

Computerized Fate and Transport Models

Many computer models have been developed to predict the fate and transport of chemicals in the environment, and computer codes for many of these are available. Several useful models are also available through the USEPA's Graphical Exposure Modeling System (GEMS), which contains transport models for groundwater, surface water and air. GEMS is designed to be user-friendly and its models can be accessed via telecommunications with the USEPA host computer. Examples of the fate and transport models available in GEMS include:
- ATM—Gaussian dispersion model for predicting contaminant fate and transport in air
- AT123D—three-dimensional model for predicting fate and transport of contaminants in groundwater
- SESOIL—unsaturated zone transport model
- EXAMS—three-dimensional model for evaluating surface water fate and transport of chemicals

Computer models generally give much more detailed estimates of environmental concentrations over time and space than are otherwise possible. They can often be used to construct maps of contaminant isopleths over time. This type of detailed environmental fate information allows greater flexibility in the risk analysis. However, these models only address one component of the risk analysis approach, and they must be integrated into the overall analytical framework for the analysis.

INTEGRATED RISK ANALYSIS MODELS: AN EXAMPLE

Another application of computers to risk analysis is the integrated risk model, defined here as a model that has all or several of the necessary components integrated into a single structure. An example would be a model that estimated transport, exposure and risk for a defined chemical release. In these models, the algorithms are linked so that risks can be calculated for a given set of inputs without the need for intermediate calculations. The RCRA Risk-Cost Analysis Model[1] would be one example of an integrated risk model, although this model is not suitable to specific site analysis.

To illustrate the concept of an integrated hazardous waste risk model, a model being developed for hazardous waste land disposal is described briefly in this section. With a few modifications, this model could be adapted for risk analysis at some types of hazar-

Chemical Name	Alternative	Type	Ground Water (mg/l) Public Drinking Water	Ground Water Private Drinking Water	Surface Water (mg/l) Recreational Creek	Air (mg/m3) Public Water Treatment Plant	Air Wellhead Treatment	Air Abatement Plant
Vinyl Chloride	A	Max.	3.1E-03	6.8E-03	0.0E+00	1.5E-01	0.0E+00	0.0E+00
		Avg.	1.0E-03	4.2E-03	0.0E+00	2.8E-03	0.0E+00	0.0E+00
	B	Max.	3.1E-04	6.8E-03	0.0E+00	1.5E-02	7.4E-01	0.0E+00
		Avg.	1.0E-04	4.2E-03	0.0E+00	2.8E-04	2.1E-02	0.0E+00
	C	Max.	0.0E+00	5.7E-05	7.8E-03	0.0E+00	0.0E+00	1.2E+00
		Avg.	0.0E+00	5.2E-05	2.9E-04	0.0E+00	0.0E+00	3.4E-02
	D	Max.	1.6E-03	5.7E-03	3.7E-02	6.2E-02	0.0E+00	5.1E+00
		Avg.	8.0E-04	4.3E-03	2.7E-04	2.1E-03	0.0E+00	3.0E-02
1,2-Dichloroethane	A	Max.	6.1E-03	1.3E-02	0.0E+00	2.9E-01	0.0E+00	0.0E+00
		Avg.	2.0E-03	8.0E-03	0.0E+00	5.4E-03	0.0E+00	0.0E+00
	B	Max.	6.1E-04	1.3E-02	0.0E+00	2.9E-02	1.4E+00	0.0E+00
		Avg.	2.0E-04	8.0E-03	0.0E+00	5.4E-04	4.0E-02	0.0E+00
	C	Max.	0.0E+00	1.1E-04	1.5E-02	0.0E+00	0.0E+00	2.5E+00
		Avg.	0.0E+00	1.0E-04	5.5E-04	0.0E+00	0.0E+00	6.5E-02
	D	Max.	3.1E-03	1.1E-02	7.2E-02	1.2E-01	0.0E+00	9.9E+00
		Avg.	1.5E-03	8.3E-03	5.3E-04	4.0E-03	0.0E+00	5.8E-02

Figure 2
Sample Data Management Format for Risk Analysis:
Chemical Concentrations

dous waste sites. The primary modifications required for this application would be in the chemical release module and in the site-specific hydrogeologic data required. The model would be most applicable to sites where groundwater is the major exposure pathway. In any case, the model's structured, logical approach to risk analysis could be applied.

Structure of the Model

The basic risk analysis approach taken in the model is similar to that described in the second section. The model is a computerized set of algorithms that projects chronic health risks over a specified time horizon for land disposal facilities. The model has four major modules linked into a continuous structure.

The failure/release module determines the year of failure (defined as release of leachate to groundwater) for a facility based on its design and location. It also estimates the annual volume of leachate released to groundwater based on a facility's design, size and climate category (defined by net infiltration). At present, the model contains several landfill and surface impoundment design types. Clay and synthetic liners in various single- and double-layer design configurations plus unlined facility designs are included. The current release module would be inapplicable to most uncontrolled waste sites, with the possible exception of sites with abandoned landfills or surface impoundments. An alternate release module would most likely have to be incorporated into the model for application at uncontrolled waste sites.

The groundwater transport module estimates chemical concentrations in groundwater and chemical loadings to surface water resulting from leachate releases by a facility. The groundwater transport module produces time profiles of concentration and mass loading at various down-gradient distances from the source. Chemical-specific mobility and persistence in groundwater are factored into the analysis. Several groundwater flow scenarios, including single- and multi-layer aquifers with a range of horizontal and vertical velocity vectors, are contained in the model. Waste site applications would need to incorporate certain site-specific data such as porosity, dispersivity, groundwater velocity and direction, unsaturated zone characteristics and aquifer thickness.

The human exposure module estimates the lifetime dose of chemical received through either groundwater or surface water sources of drinking water. A time profile of lifetime dose is derived from the chemical concentration profile estimated previously. The resulting dose profile is the quantitative representation of chemical exposure used to estimate risk.

The dose-response module calculates lifetime risks of various chronic health effects for the estimated chemical doses. Risks are estimated separately for each chemical constituent of the waste. A time profile of individual risk is produced by the module, and population risk is estimated by multiplying the individual risk profile by the population profile.

The four modules described above are linked by appropriate algorithms to form the basic structure of the risk model. In addition, the computerized model includes several input data bases from which it retrieves information and input and output modules that facilitate operation of the model and presentation of the results.

Operation of the Model

The model requires certain input variables to be specified by the user. The input variables include chemical (or waste) identity,

climate category, groundwater flow scenario, distance from facility to exposure point and population exposed. Additional inputs would be required for site-specific applications at waste sites.

The calculation sequence for a typical model analysis is shown in Figure 4. In an actual model run, this sequence is repeated as directed by the program until risk estimates are calculated for all specified variable combinations. In addition to the operating sequence, this flow chart shows the input variables and chemical-specific parameters that are factors in the major calculations.

The first step in the model sequence is determination of the year of facility failure and the leachate release rate following failure. The model then estimates the concentration of specific chemicals in the leachate and calculates a chemical release rate. The next key step is calculation of the time delay resulting from chemical passage through the unsaturated groundwater zone. At this point, the model has estimated the total time for the chemical to reach the saturated zone and the annual mass input of the chemical to the saturated zone.

The next step is estimation of groundwater chemical concentration at the specified exposure point over the time horizon. This computation is based on the groundwater flow scenario, the distance to the exposure point, the mobility and persistence of the chemical being evaluated and the chemical mass input rate previously calculated. Following this, the model calculates lifetime chemical doses. The individual risk is estimated on the basis of the dose and chemical-specific toxicity parameters. The final major step is estimation of the population risk. At this point, all of the basic output variables have been calculated. They can then be summarized, statistically evaluated and displayed in a variety of ways depending on the specific objectives of the analysis.

Applicability to Uncontrolled Hazardous Waste Sites

The illustrative model described above must be adapted for application to uncontrolled waste sites. However, with some adjustment, it contains all of the basic components necessary to estimate risk for a waste site. More significantly, the model has a flexible structure that can be adapted to different hazardous waste situations. The model is clearly most applicable to sites where groundwater contamination is the primary route of potential human exposure.

To adapt this model to an uncontrolled hazardous waste site, chemical releases from the site must be estimated. This is typically one of the most difficult problems in assessing risk at uncontrolled waste sites. Because the model is fully computerized, a range of release estimates can be rapidly analyzed and the sensitivity of risk to various release profiles evaluated. The model is well suited to sensitivity analysis when dealing with the unavoidable methodologic and data uncertainties.

Certain site-specific data would also be required for application of the model to a site. At a minimum, basic information about site geohydrology and meteorology and analytical data on the chemicals present must be available. The degree of uncertainty in the resulting risk estimates will in part be due to the quantity and quality of site-specific data available. Again, sensitivity analysis can be used to evaluate the effects of assumptions used to fill data gaps.

CONCLUSIONS

Systematic risk analysis can assist rational decision-making at uncontrolled hazardous waste sites by providing information on projected health effects resulting from chemical releases at the site.

| Chemical Name | Toxicity Data | Alternative | Type | Ground Water (mg/kg/day) | | Surface Water (Recreational Creek) (mg/kg/day) | | Air (mg/kg/day) | | | Total Exposure (mg/kg/day) | |
				Public Drinking Water	Private Drinking Water	Swim Intake	Fish Intake	Public Water Treatment Plant	Wellhead Treatment	Abatement Plant	Public	Private
Vinyl Chloride		A	Max.	9.5E-05	2.1E-04	0.0E+00	0.0E+00	3.5E-02	0.0E+00	0.0E+00	9.5E-05	3.5E-02
			Avg.	3.1E-05	1.3E-04	0.0E+00	0.0E+00	6.5E-04	0.0E+00	0.0E+00	3.1E-05	7.7E-04
		B	Max.	9.5E-06	2.1E-04	0.0E+00	0.0E+00	3.5E-03	1.7E-01	0.0E+00	9.5E-06	1.7E-01
			Avg.	3.1E-06	1.3E-04	0.0E+00	0.0E+00	6.5E-05	4.8E-03	0.0E+00	3.1E-06	5.0E-03
		C	Max.	0.0E+00	1.8E-06	6.0E-06	9.1E-07	0.0E+00	0.0E+00	2.8E-01	6.9E-06	2.8E-01
			Avg.	0.0E+00	1.6E-06	8.7E-09	3.4E-08	0.0E+00	0.0E+00	7.8E-03	4.3E-08	7.8E-03
		D	Max.	4.9E-05	1.8E-04	2.8E-05	4.3E-06	1.4E-02	0.0E+00	1.2E+00	8.2E-05	1.2E+00
			Avg.	2.5E-05	1.3E-04	8.1E-09	3.2E-08	4.8E-04	0.0E+00	6.9E-03	2.5E-05	7.0E-03
1,2-Dichloroethane		A	Max.	1.9E-04	4.0E-04	0.0E+00	0.0E+00	6.7E-02	0.0E+00	0.0E+00	1.9E-04	6.7E-02
			Avg.	6.2E-05	2.5E-04	0.0E+00	0.0E+00	1.2E-03	0.0E+00	0.0E+00	6.2E-05	1.5E-03
		B	Max.	1.9E-05	4.0E-04	0.0E+00	0.0E+00	6.7E-03	3.2E-01	0.0E+00	1.9E-05	3.2E-01
			Avg.	6.2E-06	2.5E-04	0.0E+00	0.0E+00	1.2E-04	9.2E-03	0.0E+00	6.2E-06	9.5E-03
		C	Max.	0.0E+00	3.4E-06	1.2E-05	1.8E-06	0.0E+00	0.0E+00	5.8E-01	1.4E-05	5.8E-01
			Avg.	0.0E+00	3.1E-06	1.7E-08	6.6E-08	0.0E+00	0.0E+00	1.5E-02	8.3E-08	1.5E-02
		D	Max.	9.5E-05	3.4E-04	5.5E-05	8.6E-06	2.7E-02	0.0E+00	2.3E+00	1.6E-04	2.3E+00
			Avg.	4.6E-05	2.6E-04	1.6E-08	6.4E-08	9.2E-04	0.0E+00	1.3E-02	4.6E-05	1.4E-02

Figure 3
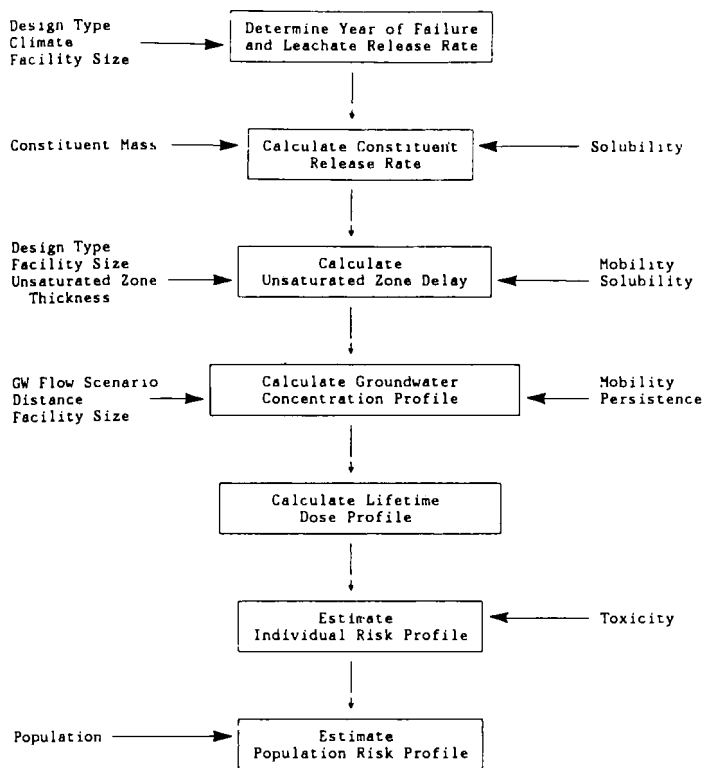Sample Data Management Format for Risk Analysis: Chemical Doses

Figure 4
Risk Analysis Model Flow Chart

Risk analysis can be used to determine the need for action at a site, to assist in selecting and designing a remedial action for a site and to evaluate the effectiveness of actions taken at a site. Risk analysis can also enlighten certain public policy questions, such as setting site cleanup priorities and evaluating overall program effectiveness.

The structured risk analysis approach outlined in this paper can provide not only numerical estimates of risk but, more importantly, can also serve as the organizational framework for a large amount of site-specific data related to potential health effects. Risk analysis, however, is not without its limitations, including inherent methodologic uncertainties and the requirement for considerable input data.

In a number of ways, computers can facilitate the risk analysis process. Computers can be used to manage the risk analysis data. Off-the-shelf computer models for environmental fate and transport of chemicals can be used to assist in the exposure evaluation, and integrated computer risk analysis models, such as the illustrative model described in the previous section can be developed and used at the site.

An integrated computer modeling approach generally permits greater breadth and depth in the analysis by reducing computation-time and allowing rapid sorting and manipulation of the data. More complex computation algorithms can be used, and more combinations of variables can be analyzed. The integrated computer model also allows a more thorough treatment of uncertainty by facilitating rapid sensitivity analysis. A disadvantage of integrated computer models is the front-end time and cost required for development. This generally makes it impractical to develop and use a fully integrated model for a single site. By developing a generic model that can be applied with slight modification to a group of sites, or by adapting existing models, this disadvantage can be overcome.

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COPING WITH UNCERTAINTY IN EVALUATING ALTERNATIVE REMEDIAL ACTIONS

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INTRODUCTION

Remedial investigation/feasibility studies (RI/FS) typically demand competent decision-making in the face of extreme uncertainty. Significant sources of uncertainty include: (1) representativeness of soil and groundwater samples taken from grossly heterogeneous media, (2) limited availability of data at critical decision points and (3) inadequate theoretical basis for evaluating contaminant fate and transport. In this paper, the authors discuss uncertainties presented by the above sources. Techniques presented in this paper are useful at several steps in the RI/FS process, including: (1) development of response objectives and evaluation criteria, (2) design of field sampling strategies and (3) evaluating costs and effectiveness of alternative actions.

Several case studies are presented. Although each case study is based on experiences of the senior author in evaluating remedial actions at contaminated sites, the examples have been simplified slightly to clearly illustrate concepts. The case studies include:
- Estimating the volume of contaminated sediments and soils in the drainageway of a large hazardous waste landfill. This study illustrates the utility of Monte Carlo-like procedures in estimating the probable depth of penetration of strongly sorbing organic chemicals and the value which can be derived from limited available data.
- Applying statistical techniques to the problem of estimating the volume of pumpage required to restore an aquifer contaminated by mixed solvents; the potential risks associated with using "best estimates" are demonstrated by this case study.
- Utilizing (and thus illustrating the value of) kriging in estimating the volume of contaminated soils and in developing sampling strategies.

CONTAMINATED SEDIMENT VOLUME ESTIMATION

A small stream received runoff from a large hazardous waste landfill which began receiving wastes in 1962. Adjacent to the landfill is a small industrial facility which also discharged cooling water, obtained from an on-site well, to the stream. The industrial discharge maintains a fairly steady flow in the stream which, under natural conditions, would be intermittent or ephemeral.

The natural groundwater elevation is 18 ft below the stream bed elevation. Thus, the stream is an artificial recharge zone from which a steady flow of water percolates to the water table at a rate determined by the permeability of the underlying soils. The most toxic contaminants associated with the site are chlorinated hydrocarbons with very high soil adsorption coefficients. Potential remedial alternatives are: (1) stream diversion and capping, (2) excavation and disposal in the landfill and (3) groundwater restoration coupled with either of the first two steps.

Critical to the evaluation of these alternatives are:
- Potential for groundwater contamination; i.e., have contaminants migrated to the water table
- Estimation of the volume of contaminated materials—a large volume argues against excavation based on cost, health and environmental risks. The surficial contamination of the bed sediments has been mapped, so the key unknown is the depth of contaminant penetration.

Contaminant Penetration

The following equation describes the depth of contaminant penetration:

$$L = \frac{T \, K^v}{n + \rho_b \, K_{oc} \, f_{oc}} \tag{1}$$

where

T = time since wastes were first stored at the landfill
K_v = vertical saturated conductivity
n = soil porosity
ρb = soil bulk density
K_{oc} = organic carbon adsorption coefficient
f_{oc} = fractional organic carbon content of the soil
L = depth of contaminant penetration

With the exception of the facility lifetime, each of the parameters of Equation 1 must be estimated. Conductivity has been measured in similar soils associated with the landfill, as well as other sites in the general area. These data appear to be log-normally distributed with a median value of 10.4 ft/yr and a log-standard deviation of 0.45. In other words, the estimated permeability is correct to about a factor of 4.

Virtually no information is available on the organic carbon content of the soils. County soil surveys, related USDA data and soils texts such as Brady[1] indicate that soils of the type found here may range from 0.1 to 3% organic carbon. The porosity also is unknown, and standard texts[1] indicate that it may range from 0.25 to 0.5

The organic carbon adsorption coefficient of the most toxic contaminants known to be present has been estimated to be 10^4. Methods and data presented by Lyman, et al.[3] indicate that the error associated with this estimate is about a factor of 8.

Monte Carlo Simulation

Two techniques which can rationally account for the uncertainty are compared. The first is the classic Monte Carlo procedure. The available data indicate that uncertainties in K_{oc} and K_v are lognormally distributed. The uncertainties in n and f_{oc} are assumed to be uniform through their full range since there is no basis for even making a "best" estimate. The Monte Carlo analysis was performed readily and at low cost using the Statistical Analysis System (SAS) on the University of Florida computer system (programming time 1 hr, computer cost $5 for N = 10,000). The results may be summarized as follows:

The median penetration depth is only 0.8 ft., but there is a 7% chance that contamination has migrated 18 ft to the water table.

Sensitivity Analysis

An alternative method of analysis drawing on the Monte Carlo philosophy, but which can be performed quickly by hand calculation, was also developed. This method short circuits the Monte Carlo procedure by sampling the distribution of the input parameters at fixed, predetermined points. This method was expected to reproduce the central tendencies of the Monte Carlo distribution, recognizing that the "tails" of the distribution (extremely unlikely combinations) would not be accurately reproduced.

The proposed method is most appropriately characterized as a sensitivity analysis which realistically incorporates the expected uncertainty distributions of the input parameters. The method is exemplified by looking at the distribution function assumed for K_{oc} (Fig. 1). In Monte Carlo analysis, this distribution is sampled randomly for input to the calculation of penetration depth. A large random sample is required to represent the distribution accurately.

In the alternative method, the distribution is sampled at predetermined percentiles, each of which represents an equal fraction of the complete distribution. For example, if four "samples" are selected they would be 12.5, 37.5, 62.5 and 87.5 percentiles. Each sample realistically represents 25% of the range. If only three were selected, they would be the 17, 50 and 83 percentiles. In the latter case, each sample represents 33% of the range. Each of the sampled K_{oc}s represents a range of values with equal probability of occurrence. Each uncertain input is sampled by the same strategy,
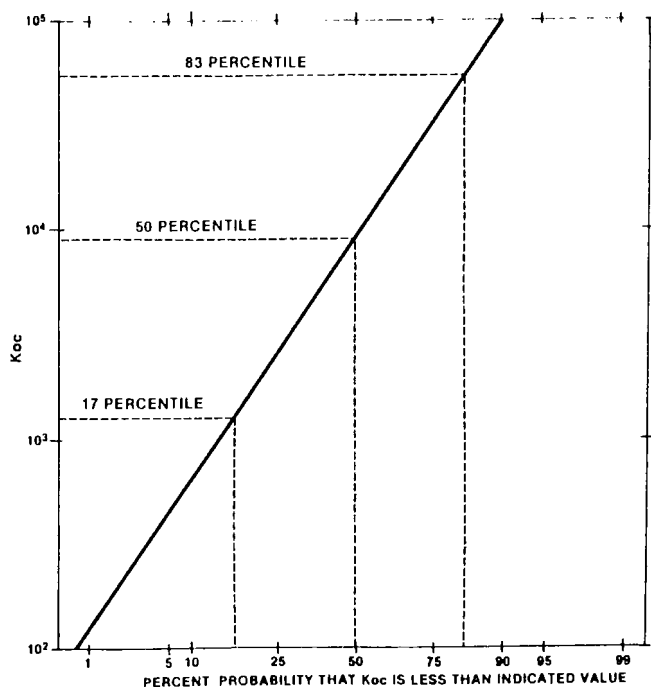
and all possible combinations of inputs are passed through the equation. For this analysis, three points were selected from each distribution, resulting in 81 (3^4) combinations of parameters and 81 independent and equally likely estimates of the penetration depth.

An advantage of this method is that fewer independent estimates of penetration depth must be calculated, thus making the analysis possible by hand and without need of a table of random numbers. The question is whether the method yields results similar to the classical Monte Carlo result. The results, which are compared in Figure 2, show the uncertainty distribution of the calculated penetration depth. It is apparent that the "short cut" method reproduces the central tendency (from 25 to 75 percentile) of the distribution accurately, but is less accurate for the less likely extremes. An alternative analysis by the short cut method, but using 256 (4^4) equally likely combinations of inputs, is not shown. that analysis showed an improvement in the 90 to 95 percentile range when compared with the 81 (3^4) calculation test.

Method Accuracy

The accuracy of the distribution is the kind of test which might interest a statistician. From a practical standpoint, though, one is interested in whether the simple method provides information accurate enough to support the right remedial action decision. By this test, the short cut method serves well. The short cut method indicates the odds that contamination has moved to the water table are 4%, while the Monte Carlo analysis indicates that the odds are 8%. Sound remedial action decisions should be insensitive to these small differences in probability. Both methods indicate the most likely depth of penetration is 0.8 ft.

Suppose, next, that a few limited soil borings were taken by hand coring methods to a depth of 4 ft and analyzed for site-related contaminants. Suppose, also, that each of these borings was contaminated through its full depth. How can this new information be used? Clearly, contamination has penetrated deeper than the best estimate; however, one must remember that the analysis indicated a 20% change of penetration below 4 ft, so it is not all that disconcerting to find contamination that deep. This new information shows that some combinations of the independently estimated values are not possible. All combinations which yield penetration depths of less than 4 ft are clearly impossible and should be deleted.

Figure 1
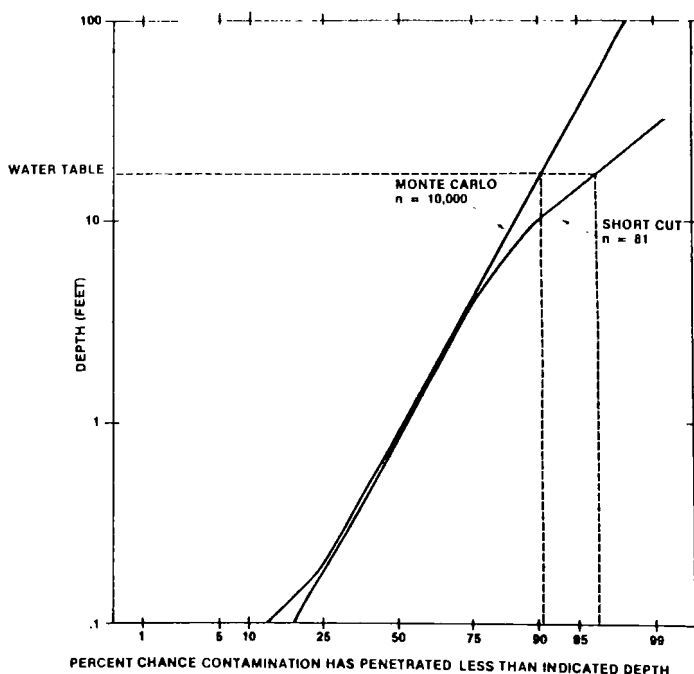Uncertainty Distribution for the Absorption Coefficient

Figure 2
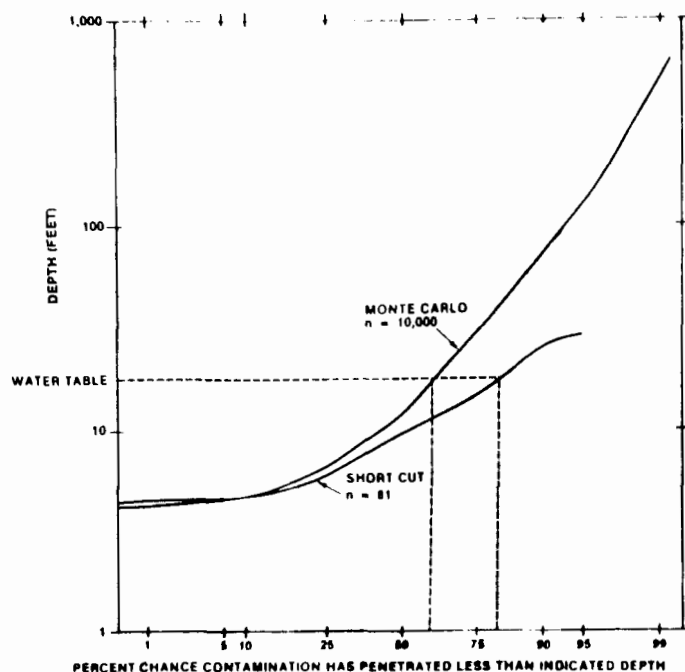Uncertainty Distribution for Penetration Depth

Figure 3
Uncertainty Distribution for Penetration Depth after Soil Analysis

These procedures were reapplied under this constraint. The uncertainty distributions calculated for penetration depth by the two procedures are shown in Figure 3. Now the best estimate depth by Monte Carlo is 11.6 ft, while the short cut result is 9.4 ft. The odds that contamination has reached the groundwater are 34% by Monte Carlo and 14% by the short cut. It is interesting that, after learning that contamination has already penetrated 4 ft, the statistical methods indicate that it is more probable that the contamination has penetrated to the water table. The methods presented here can use this data effectively.

Decisions based on "best estimates" would necessarily be confused by data in contradiction with the best estimate. Use of best estimates as inputs will lead to an estimate of penetration depth of less than 1 ft. When samples showed contamination as deep as 4 ft there would be a tendency to lose faith in such transport estimates, although they would clearly be needed to complete the assessment.

Methods based on "worst case" could not really use the new data in any meaningful way. The "worst case" estimate is that contaminant has migrated to the water table. Confirmation of penetration to a depth of 4 ft would have no influence over the decision process if "worst case" estimates were relied on.

AQUIFER RESTORATION

A spill of mixed solvents resulted in a plume of contaminated groundwater in a shallow sand aquifer. The preferred remedial action is installation of three groundwater extraction wells. The contaminated groundwater will be discharged to a sanitary sewer and ultimately will be treated in a POTW that has secondary treatment.

To properly evaluate the cost of this alternative, it is essential to estimate the volume of water which must be pumped and the duration of the pumping required before the aquifer water quality will meet acceptable water quality standards. For simplicity, this discussion focuses on benzene, one of the several solvents which currently exceeds those standards.

Measured benzene levels in the contaminated area ranged from 1 to 5 $\mu g/l$. Four sampling locations were so heavily contaminated by other solvents, however, that high concentrations of benzene could have been masked by interference. In one of these locations, the detection limit for benzene was 500 $\mu g/l$. The average concentration of benzene in the contaminated area could be as high as 200 $\mu g/l$ if an estimation is made using conservative assumptions.

A groundwater flow model was used to design an efficient shallow pumping well network to draw uncontaminated water from outside the contaminated zone through the contaminated area. One pore volume of clean water would be drawn through the contaminated zone every month with the wells in operation. The question posed was: how long must the groundwater extraction continue before benzene levels would be reduced to 1 $\mu g/l$?

The concentration in the groundwater after N pore volumes of water have been extracted, C_n, is given by:

$$\frac{C_n}{C_o} = \left(1 - \frac{n}{n + \rho_b K_{oc} f_{oc}}\right)^N$$

$$\frac{1 \mu g/l}{200 \mu g/l} = \left(1 - \frac{n}{n + \rho_b k_{oc} f_{oc}}\right)^N \tag{2}$$

$$\log 0.01 = N \log \left(1 - \frac{n}{n + k_{oc} f_{oc}}\right)$$

where C_o is the initial concentration.

The bulk density, porosity and organic carbon content of the soil ($\rho b = 1.9$, $n = 0.35$ and $f_{oc} = 0.002$, respectively) were all determined via sampling and soil characterization. The variability evident in these data could also be used in a Monte Carlo analysis similar to the one used in the first example, but for the sake of illustration, it will be ignored in this discussion. The result is sensitive to uncertainty in the K_{oc} value for benzene. Benzene's K_{oc} has been measured by Karickhoff, et al.[4] so the uncertainty is considerably less than usual for estimated values. Still, Karickhoff, et al.[4] data suggest that measured K_{oc} values are only reliable to about 20%.

The uncertainty is assumed to be log-normally distributed about a median value of 83 with a logarithmic standard deviation of 0.1. This condition may be compared with the logarithmic standard deviation of 0.78 which was used for estimated K_{oc} values in the previous case study. Using the best estimate value:

$$N = \frac{\log 0.01}{\log \left(1 - \frac{0.35}{0.35 + 1.9 \times 83 \times 0.002}\right)} = 6 \tag{3}$$

so 6 pore volumes must be drawn through the contaminated zone to achieve the cleanup standard. This will take 6 months of pumping. Given the uncertainty in K_{oc}, however, there is a 50% chance that the standard will not be achieved in 6 months. What is the "upper bound" on the required pumping time? Applying the log-normal uncertainty, one can say that one is 95% confident that the actual K_{oc} for benzene is less than 121. Then one can be 95% confident the duration of pumping required to reach standard is less than 8 months. The restoration of the aquifer will almost certainly be achieved in less than 1 year.

UTILIZATION OF KRIGING

Surficial soils at an abandoned industrial facility have been contaminated by a variety of aromatic hydrocarbons. Groundwater underlying these soils is not contaminated. For the sake of illustration, this discussion will focus on pyrene, one of several identified contaminants. Again, strictly for the purposes of this presentation, the authors will assume that the affected parties have reached agreement with regulatory authorities that the soil's cleanup criterion will be 100 ppm, based on the potential for human exposure via drinking water.

Surficial soils were collected at locations shown in Figure 4. Thirty-seven samples were taken including one 14-point transect along the long axis of the site, intersected at three points by smaller perpendicular transects. Distances between points in the transects were irregular. Seven other points were placed randomly in the field, but nearer the intersections of the transects. At each point, surficial soil samples were analyzed for the contaminant concentration.

Because environmental quality indicators often tend toward a log-normal distribution, contamination levels were log-transformed prior to statistical analysis. After log-transformation, most statistical procedures based on an assumption of normality are directly applicable.

The pattern of contamination is quite sporadic, with little spatial coherence. One location exceeds 1,000 ppm; another location exceeds 100 ppm. These sampling locations were not adjacent, and samples taken between themshow degrees of contamination varying from undetectable to 40 ppm. Such heterogeneity is common in soil sampling. Since soil contamination is often highly variable over short inter-sample distances, routine interpolation techniques can be misleading, implying considerable confidence in the concentration values at unsampled locations. To avoid such inappropriate interpretations, Environmental Science and Engineering, Inc. (ESE) has recently applied for geostatistical approach known as kriging on several assignments of this type.

Kriging Theory

Kriging is a method of interpolation based on the theory of regionalized variables. Regionalized variables are those variables that vary geographically, such as rainfall, metal content of an ore body or, in this application, soil contamination levels. The advantage of Kriging over other interpolation methods is that it is optimum and unbiased. The greatest benefit is the fact that it calculates an error for each estimated point.

Kriging makes use of the semi-variogram, a graph of the average differences (semi-variance) between pairs of points at increasing separation distances. Theoretically, the semi-variance increases with separation distance from 0 to a value equal to the population variance. The inter-sample distance at which the semi-variance

levels off at the value of the population variance is called the range. Inside the range, pairs of points are somehow correlated; outside the range, they are independent. Kriging is best used when the distances between the points to be estimated and the measured values are shorter than the range.

Kriging was used to contour map the boundary between contaminated and uncontaminated soils. Since all soils contaminated above standard might have to be excavated, realistic estimates of the area had significant cost implications. Kriging was used to maximize the investigators' certainty of the contour lines to minimize the costly chances of excavating uncontaminated soils.

Semi-Variogram Estimation

The semi-variogram estimation and universal Kriging program[5] was used in this study. It consists of several options enabling the user to calculate semi-variograms, test goodness-of-fit (GOF) of the calculated semi-variograms to the population and estimate point or area values.

The semi-variogram was calculated, and a smooth function was fit using a spherical model. Without going into further detail (see the article by Gambolati and Valpi[6]), the parameters used to fit the semi-variogram implied that: (1) points sampled closer together than 200 m were correlated; (2) the variance of the population was approximately 1.26 log units; (3) 38% of the variance was attributable to spatial variations; and (4) 62% of the variance was either random or could not be accounted for by the sampling scheme. The latter part of the variance is usually called the nugget variance or nugget.

KEY

☐ CONTAMINATION PRESENT
▲ SHALLOW SOIL SAMPLE

Figure 4
Sampling Grid

KEY
▓ 10-100 ppm
▒ 1-10 ppm
☐ <1 ppm
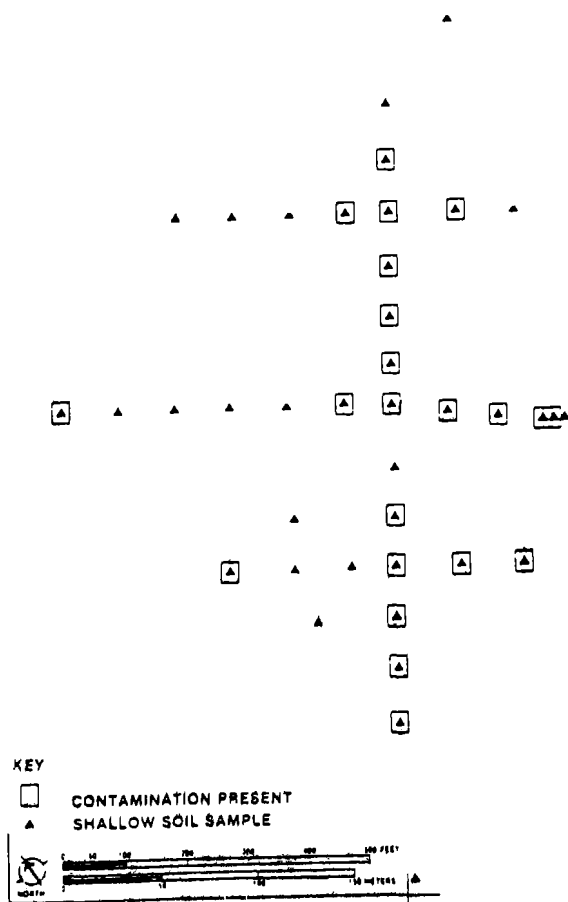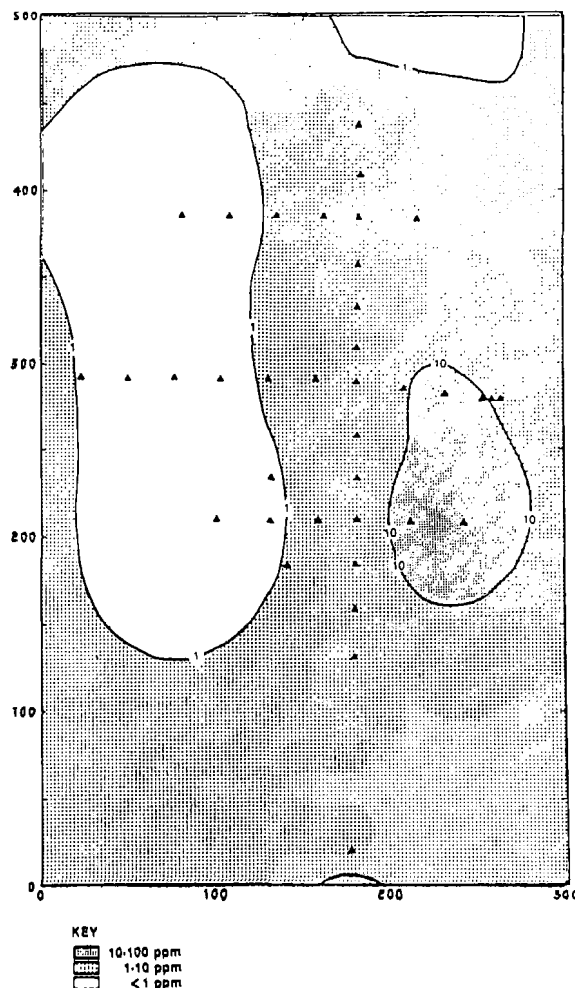
Figure 5
Estimated Soil Contaminant Distribution by Kriging

GOF tests involved the sequential removal of each data point, replacement of that point by Kriging using the semi-variogram equation and neighboring points, and comparison of real versus estimated points. A good fit was indicated if the average difference between Kriged and real points was near 0 and if the reduced mean square error (mean square error divided by the variance of the estimate) approached one. In this study, the average error was -0.013, and the reduced mean square error was 0.964.

About every 17 m 396 points were Kriged (interpolated) in the x direction and 23 m in y. The x-y locations and Kriged z's were input to Surface II, a computer graphics package for contour mapping. A very simple map was drawn (Fig. 5) using contours 1, 10 and 100 ppm.

Even though two data points had values greater than 100 ppm, the Kriging system did not reproduce them. The Kriging system regarded these two values as being anomalous, indicated by the large value of the nugget variance. When the nugget is large, the Kriging system tends to smooth the data. In this case, the smoothing was excessive when compared to the actual data.

To avoid this excessive smoothing, a new data set was: (1) created by including the measured values as well as the Kriged values and (2) used for a new contour map (Fig. 6). Areas of the map with values less than 1 ppm and values between 10 and 100

ppm were enlarged, and an area of values greater than 1000 ppm was defined.

Uncertainties

The differences between Figures 5 and 6 indicate an uncertainty in the placement of the contour lines. The error estimates at each interpolated point were contoured in Figure 7. The errors represented one standard deviation for each estimate. The contours genrally indicated that error increased with distance away from the central location of the sample points. The greatest errors were located in the corners of the map where samples had not been taken.

The best estimate and error estimate can be combined to estimate the upper bound of the contaminated zone. The upper bound of the contaminant levels at 90% confidence is shown in Figure 8. The values were determined by adding 1.28 times the standard deviation to the best estimate. A logarithmic standard deviation is 0.47, indicated by the variance of replicate soil samples, was used for actual sample data points. The area with values greater than 100 ppm grew from about 0.1 acres in Figure 6 to about 6 acres.

Recognizing that soils exceeding 100 ppm must be addressed via a remedial plan, the comparison of Figures 6 and 8 indicates the high level of uncertainty. The high level of uncertainty also indicates a

KEY

100-1,000 ppm
10-100 ppm
1-10 ppm
<1 ppm
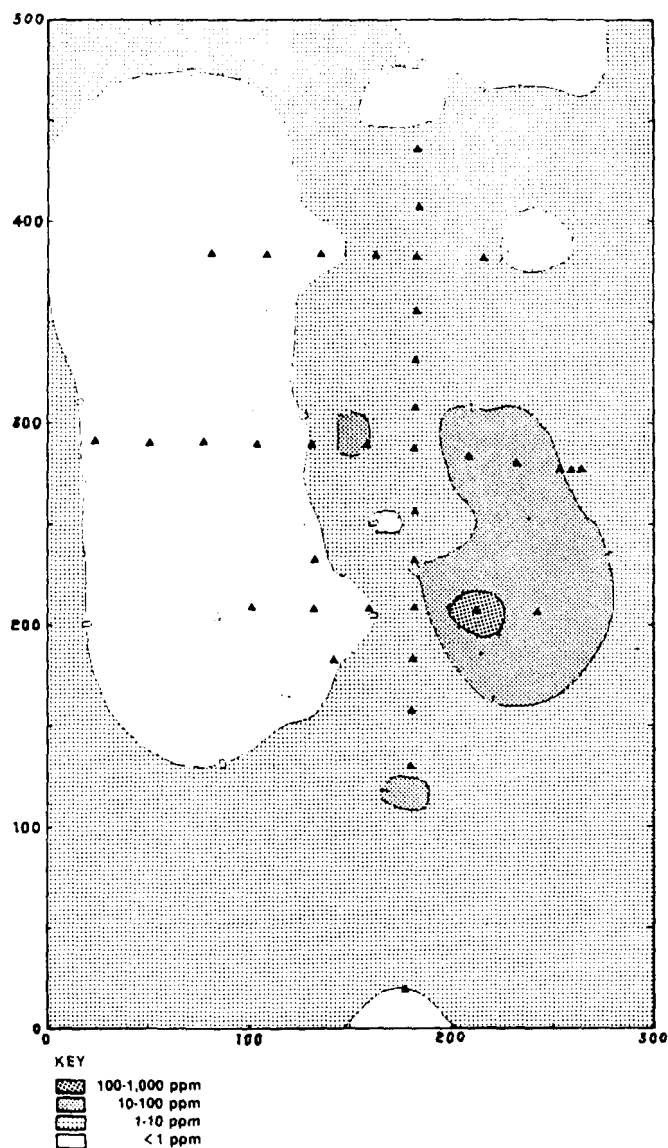
Figure 6
Best Estimate of Contaminant Distribution Based on Kriged
Estimates and Actual Data

KEY

UNCERTAINTY
LESS THAN
FACTOR OF 10

UNCERTAINTY
GREATER THAN
FACTOR OF 10
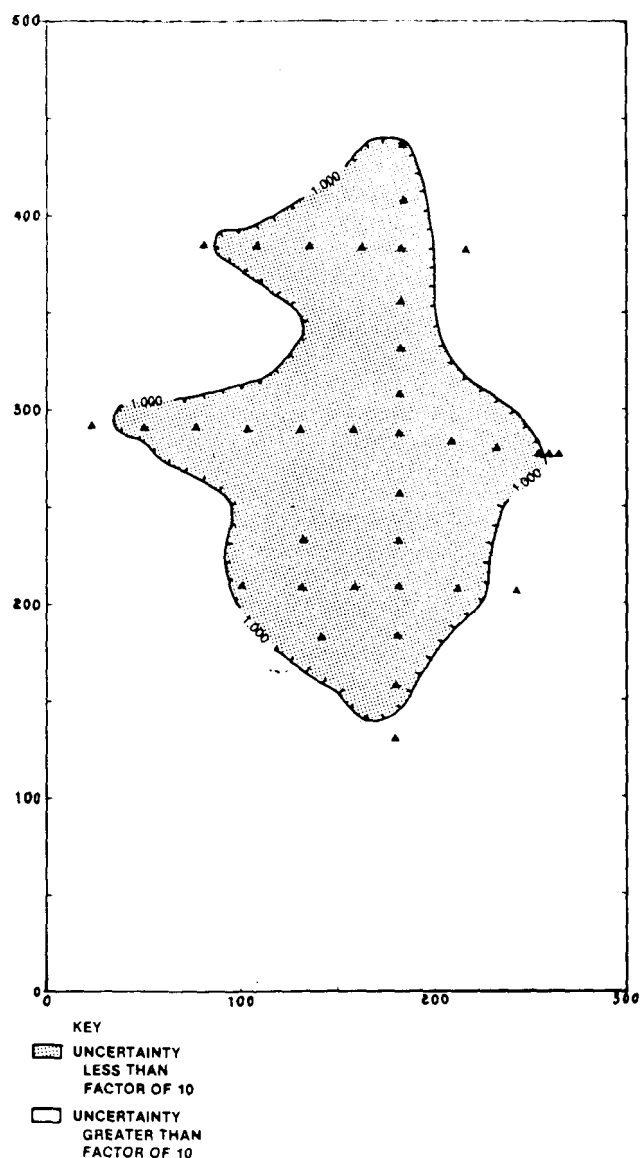
Figure 7
Distribution of Errors Associated with Kriging

need to further sample to either redefine the 100 ppm contour or just to increase the certainty of estimates about that contour.

The clearest way to illustrate the extent of uncertainty regarding whether soils are above the cleanup criterion is to plot (Fig. 9) the number of standard deviations between the best estimate value and the criterion (100 ppm). For example, if the best estimate is 5 ppm and the uncertainty in that number is a factor of 5, one is still relatively confident that the soil does not require cleanup. If the uncertainty were a factor of 50, then it would be hard to guess whether that soil would require action.

In log units, the first example has a best estimate of 0.7 and a standard deviation of 0.7, the latter has a standard deviation of 1.7. Since the log of the criterion (100 ppm) is 2, the estimate is 1.9 standard deviations below the criterion in the first case. In the latter case, the estimate is 0.8 standard deviations from the criterion.

The parameter

$$C = [\log (\text{criterion}) - \log (\text{estimate})] / \text{logarithmic standard deviation} \quad (3)$$

is directly related to the confidence that the soils are below criterion. Large negative values ($C < -1.28$) indicate soil contamination levels significantly above the criterion. High positive values ($C > 1.28$) indicate no further requirement for sampling because soil contamination levels are significantly below the criterion.

Areas for which the absolute value of C is less than 0.68 are areas where there is very little basis for guessing whether the soils are above or below the criterion. In areas where the absolute value of C is greater than 0.68 but less than 1.28, there is a better than 75% but less than 90% change of guesins whether the soils are within standard. Thus, areas where $|C| < 1.28$ probably warrant further sampling, with most intensive sampling warranted where $|C| < 0.68$. based on this analysis, supplemental sampling locations were recommended as shown on Figure 9.

CONCLUSIONS

Statistical analysis procedures can be valuable tools to support remedial alternatives evaluation. The identification of appropriate procedures and fruitful application of those procedures requires a familiarity with the range of procedures available and the nature of uncontrolled site management issues. The first example illustrates the adaptation of Monte Carlo-like procedures to the estimation of the volume of contaminated sediments below a discharge stream from a hazardous landfill and the probability that the contaminants

KEY

- ■ >1,000 ppm
- ▨ 100-1,000 ppm
- ▤ 10-100 ppm
- ▤ 1-10 ppm
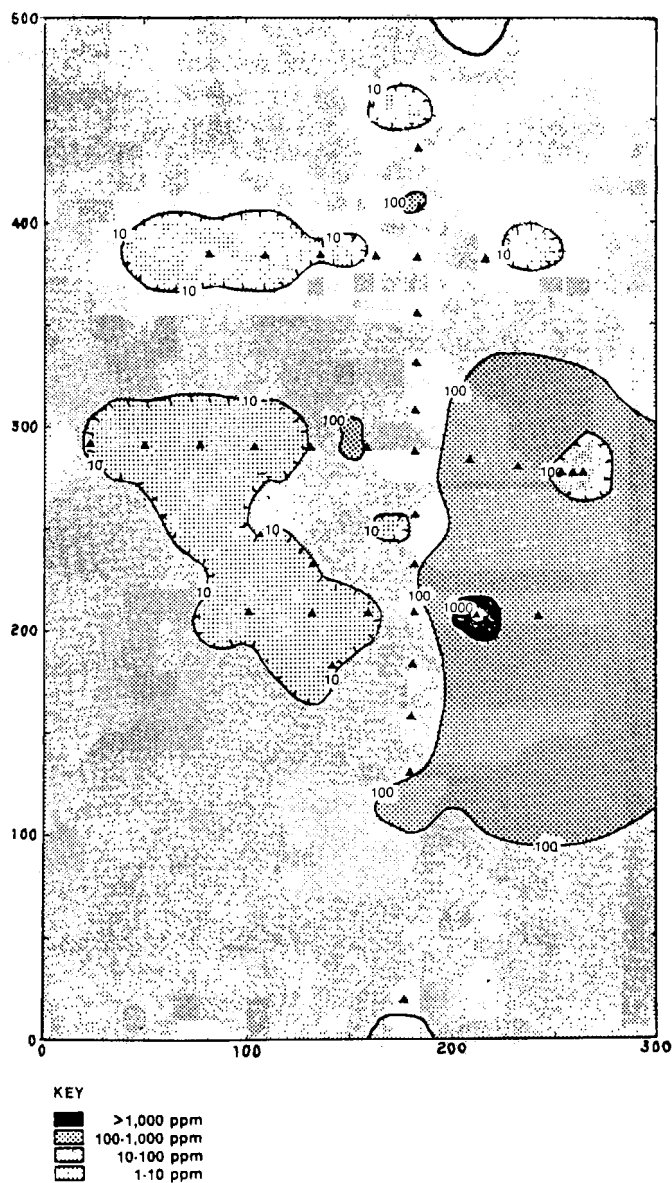
Figure 8
Conservative Estimate of Contaminated Distribution; 90% Confidence

KEY

- ▢ 90% CONFIDENCE ABOVE STD
- ▨ 75% CONFIDENCE ABOVE STD
- ▢ UNCERTAIN
- ▨ 75% CONFIDENCE BELOW STD
- ▨ 90% CONFIDENCE BELOW STD
- ▢ 95% CONFIDENCE BELOW STD
- ■ 99% CONFIDENCE BELOW STD
- ● ■ RECOMMENDED ADDITIONAL SOIL SAMPLING LOCATIONS
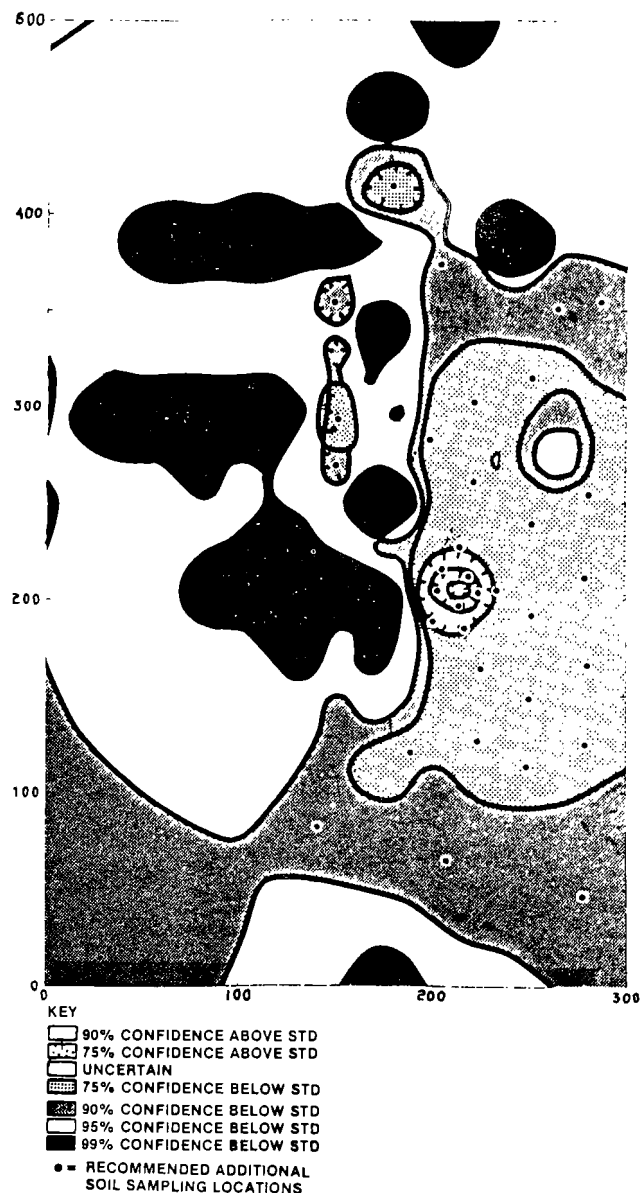
Figure 9
Confidence Zones with Respect to Soil Cleanup Criterion and Recommended Sampling Locations to Improve Confidence

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have reached an aquifer. Adaptation of these procedures to different amounts and qualities of environmental data was demonstrated in both that case study and the second case study which evaluated the probable duration of pumping required to restore groundwater quality. The results are directly applicable to remedial action decisions.

In a third case study, the geostatistical procedure known as kriging was used to demonstrate that the results of limited sampling were inadequate to define the volume of "actionable" contaminated soils. Kriging was also used to guide further sampling efforts. In that evaluation, useful methods of presentation of the statistical results were developed. This method of presentation makes the complex statistical results more accessible and effective in influencing the decision process.

The case studies support the following conclusions regarding uncertainties associated with soils and subsurface contamination:

- Uncertainties regarding the adsorption process are severe and often allow no better than order of magnitude estimates of contaminant migration potential.
- Uncertainties regarding the permeability of soils can also lead to substantial uncertainties in estimating contaminant migration, though these uncertainties are typically less serious than those regarding adsorption.
- When the effects of uncertainty in both adsorption and permeability are combined, extreme uncertainties in contaminant migration estimates must be expected and recognized.

- The uncertainty in many environmental variables appears to be best described by a log-normal distribution; although these data were not presented in this paper, such distributions are apparent for contaminant concentrations, alternative estimates of adsorption coefficients and measurements of soils permeability in the same hydrogeologic unit. Log-transformation of environmental data frequently permits the application of statistical procedures which have been derived upon the assumption of normality.

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DESIGNING RISK ANALYSES TO AVOID PITFALLS IN COST RECOVERY ACTIONS: A LEGAL/TECHNICAL SOLUTION

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INTRODUCTION

Over the past decade, a significant amount of legislation has been passed to protect the American public from the adverse effects of toxic substances.[1] Some of these laws are relatively easy to implement since Congress provided clear legislative tests to determine when and to what extent regulation is appropriate. For example, the Federal Food, Drug and Cosmetic Act avoids many difficult regulatory decisions by forbidding the intentional addition of any substance that has been shown to induce cancer in humans or other animals.[2] The justification to regulate under this Act need not include a determination that the carcinogenic substance poses an unreasonable risk, because the statute establishes a no-risk standard. The applicability of animal bioassays to humans is not questioned, and the FDA does not have to analyze whether cancers are likely to occur at doses below the level of exposure that caused cancers in the animal tests. The basis for regulating under this statute is rather straightforward.

CERCLA,[3] which is the most recent legislation addressing toxic and hazardous wastes, adopts a similar direct approach. Through implementing guidance and judicial decisions, it has become evident that responsible parties/defendants bear a considerable burden to avoid the reach of the statute.[4] Superfund authorizes governmental action which substantially impacts regulated entities in the interest of protecting the public health and permits institution of lawsuits against the culpable parties to recover the reasonable costs of solving the waste problem. It is significant that government is granted broad discretion to exercise its judgment[5] in performing risk analyses to determine whether an imminent and substantial endangerment exists and in developing solutions to these problems. These governmental determinations are limited only by the National Contingency Plan,[6] which becomes the basis for justification for expenditures. The responsible parties/defendants have limited opportunity to challenge these costs and far less opportunity to attack the bases for such expenditures, i.e., the risk analyses performed by the government and its contractors.

Although CERCLA provides a strong regulatory framework for addressing threats posed by hazardous wastes, the "how clean is clean" issue still presents a vexing problem to the USEPA. Unlike the water or air programs where a single medium is being assessed, Superfund sites typically have several routes of exposure; single media standards are of little use. Attempts to address this issue have centered on use of site specific risk analyses that assess all routes of exposure to quantify the magnitude of the threat present and evaluate the reliability and protection offered by various response alternatives. This type of multi-media analysis is on the cutting edge of science and, consequently, numerous questionable

assumptions are used to arrive at a final decision. It is not unusual for only a few assumptions to make the difference between choosing a no action alternative and a $10 million response action. However, for the USEPA to cover the cost of a response action based on such assumptions, a cost recovery action is necessary. Although there has not yet been a sizeable body of case law, the courts are expected to accord substantial deference in review of disputes risk analyses if the recent trend of Superfund case law continues. To gain insight into how courts may review Superfund risk analyses in a cost recovery action, a review of court decisions involving similar regulatory actions is appropriate.

A review of most other environmental statutes regulating toxicant levels in the work place, home or environment reveals that most statutes are similar to the Superfund program; a threshold risk should be present to justify initiating Federal response. These statutes usually require a determination of unreasonable risk and an evaluation of the economic consequences of abating the "unreasonable" risk.[7] Such statutes include the Consumer Product Safety Act (CPSA),[8] Resource Conservation and Recovery Act of 1976 (RCRA),[9] Occupational Safety and Health Act of 1970 (OSHA)[10] and the Toxic Substance Control Act (TSCA).[11]

It is important to realize that most toxics statutes are quite recent developments. Prior to their enactment, agencies did not focus resources to develop the expertise and detailed information required to conduct comprehensive analyses of toxic substance impacts. In the early case law, the courts realized that many issues in the toxics field were "on the frontiers of science", and, therefore, gave substantial deference to agency decisions if there was an apparent need to regulate.[12]

Substantial deference was not only characteristic in reviewing risk analyses but also in conducting other complex environmental assessments. One fairly exhaustive review of cases involving complex environmental models used in air, water and noise pollution projection concludes that "courts in reviewing environmental cases involving computer models and other quantitative methodologies have been constrained to apply a [sic] too limited and differential standard of review in those decisions."[13] This reflected the judiciary's lack of expertise and exposure to the complicated problems these analyses attempt to evaluate.

However, a review of the recent case law indicates that courts are now willing to conduct a more searching and thorough review of the record upon which an agency has based its decision.[14] This trend is no doubt a sign that the regulated community has become more astute in dissecting agency analyses and perfecting its attacks on complex reasoning. The judiciary has become either more familiar with the topics or more sympathetic to the arguments raised by

those subject to regulation. We can expect nothing less in consideration of the anticipated challenges to decisions (and their costs) prompted by risk analyses performed under Superfund.

Since demands for accurate risk assessments have increased, significant scientific improvements in testing exposures and effects of toxic substances are being developed and verified at a rapid pace.[15] As a result of the recent expansion in scientific understanding, some courts appear to believe that risk evaluation has become a "precise" science and that demands upon the regulatory agency for detailed technical justification should, therefore, be increased.[16] However, this assessment of the state of the art is superficial if the volume of law review articles on uncertainty in risk assessments is an accurate barometer of scientific capabilities.[17]

The purposes of this paper are to provide an indication of the level of judicial review that one may expect for the various components of a risk analysis performed for a Superfund site and to put into context some important issues that are likely to arise in Superfund enforcement and remedial action cases. In this paper the author first reviews the general standard of judicial review applicable to most risk analyses and then goes step by step through the factors necessary to formulate a thorough risk analysis. The author also evaluates the specific standard of review for each step. The following pieces of the risk assessment puzzle will be explored:
- Data Base
- Model Selection
- Exposure Assessment
- Demonstration of Risk
- Quantification of Risk

For each component of the risk analysis, a review of existing case law will be presented and compared with the findings of a recent judicial decision in the risk assessment field, *Gulf South Insulation et al. v Consumer Product Safety Commission*, (the "Foam Insulation" Case).[18] This case is used for comparison because it provides an excellent example of how thorough courts may be in reviewing risk analyses. To briefly summarize, the *Gulf South* case was brought in response to a proposed ban on urea-formaldehyde insulation. In April, 1982, after a six year investigation into the effects of urea-formaldehyde foam insulation (UFFI), the Consumer Product Safety Commission (CPSC) issued a final rule banning UFFI in residences and schools. The CPSC found that UFFI posed an unreasonable risk of acute irritant effects and cancer. The Fifth Circuit's review of this rulemaking evaluated virtually every factor of the CPSC risk analysis for UFFI and concluded that the analyses and methodology were insufficient to support the necessary finding that an "unreasonable risk" was present.

STANDARD OF REVIEW

Prior to an investigation of an agency's decision-making record, the court must determine the appropriate standard of review to apply. Some statutes regulating carcinogens specifically state the level of judicial scrutiny which agency regulations must pass. For example, section 2060 (C) of the CPSA states that a consumer product safety rule shall not be affirmed "unless the Commission's findings...are supported by substantial evidence on the record taken as a whole." In *Industrial Union Department, AFL-CIO v. Hogdson*, the court states that under the substantial evidence test, "our review basically must determine whether the Secretary carried out his legislative task in a manner reasonable under the state of the record before him."[19] This is the concept of "reasoned decision-making" which has evolved as the common standard for judicial review of agency regulatory action.[20]

In determining whether or not a decision will meet the reasoned decisionmaking test, the court assesses the agency's action in light of the statutory directive under which the regulation or action is promulgated.[21] In certain situations, the statutory language or legislative history may be used by the agency as partial justification for deciding an issue or interpreting data when two or more answers are plausible.[22] For instance, a decision to regulate an uncertain cancer risk is more likely to be affirmed if the statute specifies that "an ample margin of safety to protect public health"[23] is required,

than if the statute requires "that necessary to protect human health and the environment", all other factors being equal.[24] Latin stresses that this is especially true when evaluating decision making under uncertainty.[25] In *American Textile Manufacturers Institution v. Donovan* (the Cotton Dust Case), the Supreme Court held that the Occupational Safety and Health Act defined the balance that Congress desired when balancing risks to workers and costs.[26] Worker health was placed above all other considerations. Thus, the court allowed the regulatory authority to err on the side of overprotection when the information presented was conflicting or not conclusive.

The court in the *Foam Insulation Case* described this level of review in more detail. "The facts that detract from the Agency as well as those that support it are to be considered (cites omitted)... the ultimate question is whether the record contains such relevant evidence as a reasonable mind might accept as adequate to support a conclusion (cite omitted)."[27] Review of the UFFI decision shows that the Fifth Circuit applied the substantial evidence/reasoned decision-making test to each and every decision.

Although one cannot voice disagreement with the Fifth Circuit's choice of judicial standard of review, most courts apply this test to the record as a whole, and not to each and every point of the CPSC analysis. To do so amounts to a substitution of judgment by the reviewing court; such action has been strongly discouraged by the Supreme Court since *Vermont Yankee*.[28] However, the First Circuit decision appears to appreciate that numerous small "errors" in a risk analysis can rapidly compound and produce an unreasonable result. For this reason, a more thorough review may be justified if the record supports it.

In reviewing the application of the substantial evidence/reasoned decision making test in the *Cotton Dust Case*, the Supreme Court states that "the possibility of drawing two inconsistent conclusions from the evidence does not prevent the administrative agency's finding from being supported by substantial evidence (cite omitted)."[29] If the test were not applied in this fashion, it would require almost flawless decisionmaking by the regulatory agency. This requirement, of course, would be virtually impossible to meet.

In reviewing the OSHA analysis finding that a carcinogenic substance posed an unreasonable risk, the Supreme Court held in the *Benzene Case* that the substantial evidence test requires an agency to prove that the specific level of exposure "more likely than not" presents "a significant risk of material health impairment."[30] In this case, the Agency could not demonstrate that the existing standard posed an unreasonable risk of a material health impairment.

A recent article on the review of reasoned decision-making and the substantial evidence test as applied to risk analysis suggests that the standard "imposes three primary responsibilities on an agency assessing health risks: (1) it must adequately evaluate the technical data; (2) it must follow proper administrative procedures; and (3) it must correctly carry out its statutory mandate."[31] This scheme reflects the framework that the Supreme Court established in *Citizens to Preserve Overton Park, Inc. v Volpe*, a framework that was structured to accommodate science-policy decisions.[32]

Most federal courts of appeal have declined to apply the substantial evidence test to certain "legislative like" policy decisions that must be made in a risk assessment, such as choice of an allowable exposure level.[33] The logic behind this decision is that when an agency is faced with a lack of available evidence to specifically support one value over another, a "science-policy" decision has to be made. These specific decisions are not amenable to review under the substantial evidence test since they are not issues of fact. In this situation, a rational basis test similar to the "arbitrary and capricious" standard of judicial review is applied.[34] This distinction in the type of decision being made is critical in the hazardous waste area because data on effects of substances are often sparse and final decisions are based on a combination of scientific fact, legislative mandate and agency policy.

From the available case law, it appears that courts apply a flexible standard of review depending upon the type of agency decision. In deciding whether or not an agency decision meets the

"substantial evidence/reasoned decision-making test," one must first decide what type of issue is present (factual or legislative/policy) prior to applying the test. When legislative/policy decisions are involved, greater deference is given. This approach to review of agency decision-making recognizes that many regulatory decisions are comprised of factual and non-factual decisions, and that the standard of review should reflect the nature of the agency's decision.

DATA BASE

A risk analysis, like any other scientific analysis, must be based on reliable scientific information to produce reliable results. The agency should be convinced that the data are not biased, are appropriate to the situation being analyzed and are the best that can be readily obtained. When data are conflicting, the agency should explain why the data were chosen and other data omitted. Where the agency has explained its rationale for selecting data, courts typically allow the regulatory agency significant discretion because of the complexity of issues influencing the decision on appropriate data.[35]

In most risk analyses, significant data gaps are present. For this reason, a major issue on review is often whether or not the data base is sufficient to draw a reliable conclusion. In the *Cotton Dust Case*, the Supreme Court refused to overturn OSHA's regulation on the claim that various industry and private consultant cost estimates were all unreliable. The Court found that the precision of the estimates was limited by the absence of adequate industry data to develop more reliable estimates. Because the agency could not obtain more data, it acted reasonably in using what it believed to be the most reliable data.[36] This position has been espoused on numerous occasions by the lower Federal courts. Where the agency "recognizes" the thinness of the data base and explains "the reasons and its efforts to compensate therefore," the courts will not second-guess the agency.[37] If deference was not given in this area, decisions to regulate toxicants would rarely survive judicial review due to lack of data.

In the *Foam Insulation Case,* the court stated that there were numerous problems with the data base. These included: (1) the risk assessment was based on a biased sample of "complaint homes," (2) the Commission erred in relying exclusively on rat data for its risk assessment model and (3) the Commission ignored numerous epidemiological studies that indicate formaldehyde is not a human carcinogen.[38] In addition, the court stated that the Commission did not explain its reliance on a data base comprised largely of complaint homes.[39] The court concluded the studies were inadequate to serve as a data base for the risk assessment.[40]

If these concerns were accurate, potentially there would be a serious problem with the rule-making. However, the Commission did explain its use of the data base very carefully, including its reasons for relying on the rat data (though it did not use it exclusively as the court stated) and its rationale for finding the existing epidemiological studies unpersuasive.[41] The apparently flawed review by the Fifth Circuit underscores the reason why most courts do not rigorously assess the agency's selection of the data base unless major flaws are apparent. Given the court's limited personnel, expertise and time for review, one can hardly expect it to become as familiar as the regulatory agency with the strengths and weaknesses of the individual pieces of information presented to the agency for consideration.

Even if there were substantial issues surrounding the choice of data used in an analysis, courts rarely substitute their judgment for the views of the agency on the relative merits of the data, so long as the agency has explained its reasons for using the data. In the *Lead Case*, the D.C. Circuit Court stated that "where the Agency presents scientifically respectable evidence which the petitioner can continually dispute with rival...evidence, the court must not second-guess the particular way the Agency chooses to deal with the conflicting evidence and resolve the dispute."[42] Other Circuits also hold similar views.[43]

Thus, case analysis indicates that rather broad discretion is permitted an agency in its selection of appropriate data; however, that selection must be accompanied by a detailed explanation of how and why these data were chosen. Actually, this amounts to no more than good scientific documentation that would be expected of any reliable technical analysis.

MODEL SELECTION

In every quantitative environmental assessment, including risk assessment, an appropriate model must be chosen to characterize the data and project results. Models range from rather simple, incorporating only a few major factors that influence the phenomenon, to extremely complex, incorporating many factors. This characterization should not lead the reader to believe that the more complex model will always yield better results. Depending upon the complexity of the situation and the decision to be made, the proper choice of model will vary.

The inherent assumptions found in the model will, at times, be subject to judicial review. Assumptions may be built into the model to decrease its complexity or may result from a lack of knowledge concerning the phenomenon being modeled. The distinction is important because greater deference will be granted to decisions based on uncertainty than to decisions based on convenience.[44]

Similar to the deference granted an agency in selection of a data base, an agency's selection of the appropriate model is rarely questioned by the courts. In *BASF Wyandotte Corp. v. Costle,* the First Circuit states, "we agree with the Fourth Circuit, the choice of statistical methods is a matter left to the sound discretion of the Administrator....the choice of any given method may mean that an alternative would yield different results. The necessary corollary, however, is that any other system chosen would be left to the same criticism. We will not leave the Agency so vulnerable."[45]

An important consideration in judicial review of model selection is the degree of scientific knowledge available to model the subject in question. Lack of knowledge in the risk assessment area may require the agency to make numerous scientific assumptions, not all supportable with substantial evidence. As stated in *Industrial Union Dept. v. Hodgdon,* "where existing method or research is deficient, the agency enjoys broad discretion (to regulate) on the best available information."[46] When there exists uncertainty over the type of model to use, the decision to choose one model over another is a science-policy decision, not a factual one. As such, greater deference should be accorded the decision.

The court in the *Foam Insulation Case* goes substantially beyond the level of review that other Circuit courts invoke when reviewing the choice of model. The court stated that use of a "no threshold" model to predict the likely incidence of cancer is "of questionable validity."[47] This conclusion is reached in spite of the fact that the National Academy of Sciences Committee on Toxicology concluded that there was no threshold for the irritant effects of formaldehyde.[48] In addition, the Chemical Industry Institute for Toxicology study, reviewed by the Federal Panel on Formaldehyde, concluded that formaldehyde should be presumed to pose a carcinogenic risk to humans.[49] It is also commonly accepted that carcinogens do not have a threshold exposure level since science is not capable of adequately defining it at this time.[50] Based on these facts, one would hardly describe CPSC's decision to use a no threshold model as "questionable." Rather, it appears to be well reasoned and supported by a body of respectable science. The Fifth Circuit's comments on the model selection do not appear to be well founded.

One may conclude from the cases reviewed that the choice of a specific risk assessment methodology will be rarely second-guessed as long as the applicability of the model is reviewed, the primary variables are accounted for and the ability to make better projections is discussed.[51]

EXPOSURE ASSESSMENT

An exposure assessment is the phase of a risk analysis that attempts to evaluate the various routes and conditions under which

exposure occurs or is likely to occur. The level of total exposure to the toxicant is estimated at this point. Once the total exposure is calculated, the effect from that exposure may be quantified by comparing the result to the risk assessment model output. Since an exposure assessment is primarily a factual determination, substantial evidence must support the findings.

As the following case analysis will demonstrate, courts are more comfortable questioning this part of a risk analysis than any other. This appears to occur because exposure analyses are easy for laymen to understand and are not particularly technical in nature. From our own experience, we can assess whether or not a particular exposure scenario is reasonable. For example, assuming that a person stands at the maximum point of concentration 24 hr a day, 365 days a year for 70 yr sounds highly improbable. One would question, what about rainy days, or sending the children to school seven hours a day for 12 yr? Should not these factors require an adjustment to the predicted exposure? Due to a common sense approach that is applicable to this part of the risk analysis, courts are not hesitant to question the exposure analysis.

The first step in the exposure assessment is evaluating the routes of exposure. The primary routes of human exposure include ingestion, absorption and inhalation. In the *Benzene Case*, the Supreme Court rejected the dermal contact standard set by OSHA that was intended to reduce potential cancers caused by absorption.[52] The Court found that OSHA's exposure assessment for this route was "based on the assumption that [benzene] can be absorbed through the skin in sufficient amounts to present a carcinogenic risk" rather than on evidence showing that absorption may actually occur.[53] The lower court found that "the record fails to demonstrate that benzene is absorbed through the skin."[54] Thus, it appears that the regulatory authority must establish with substantial evidence that an exposure route is reasonably likely to occur before including it in the exposure assessment.

Another concern in reviewing the exposure assessment is assuring that the population to be protected has a level of exposure similar to the population measured. In *Texas Independent Ginners Association v Marshall*, OSHA tried to apply a risk analysis developed for different workers at different exposure levels where the only similarity was the route of exposure that was present.[55] However, the Fifth Circuit refused to apply an OSHA standard developed from data and analyses based on cotton dust levels inside mills to dust levels in ginning operations. Due to "significantly different conditions and significantly different exposure levels" for the ginning workers, the court held that OSHA failed to demonstrate that existing working conditions posed a serious health threat.[56]

The factors evaluated in the *Texas Ginners* case were very similar to the factors considered in the "technology transfer" cases under the Clean Water and Clean Air Acts.[57] In these cases, the courts required the USEPA to prove that technologies used in one type of operation will also be feasible and will achieve the proposed effluent reductions in another industrial application. Normally, significant similarities such as composition of waste, strength, process variability, etc., must be demonstrated between the different industrial wastes and operations before the court will accept the agency's conclusion that the analysis conducted for one group is applicable to another.[58] There is, however, considerable precedent where an agency data transfer has been upheld, even when the applications are dissimilar. In *Reserve Mining Company v EPA*, the court permitted the USEPA to regulate discharges of asbestos fibers into the waters of Lake Superior based on inhaled asbestos levels known to cause serious harm.[59] Clearly, this was not the same route of exposure known to cause cancers nor was the level of exposure reliably calculated to be the same proven to cause cancers.[60] The action was supported as "a precautionary and preventive measure to protect public health."[61]

Overestimating the exposure level may also invalidate the agency's risk analysis. In the *Foam Insulation Case,* the court stated that "the failure to quantify the risk at the exposure actually associated with UFFI is the finding's Achilles heel."[62] The court indicates that CPSC had overcalculated the potential exposure that would normally be encountered because they relied primarily on data from complaint houses.[63] The court also stated that the conditions tested "reflected conditions similar to an unheated, unairconditioned home, not an average home."[64] Finally, the court rejected the extension of the UFFI ban to schools because persons at academic institutions would not have the same duration of exposure assumed in the risk assessment model (16 hr a day, 7 days a week for 9 yr).[65] Thus, the court points out several important requirements for the exposure assessment: (1) accurate reproduction of exposure level for subject population, (2) similar conditions to "real world situations" and (3), in the case of a "transferred" analysis, relatively similar conditions (i.e., level and duration of exposure).

Although the court in the UFFI case does point out valid areas of concern, its factual analysis missed the mark. As previously stated, CPSC did not, in fact, rely primarily on complaint homes to develop the exposure level. The Commission undertook a rigorous statistical analysis to determine whether or not complaint homes had significantly higher levels of formaldehyde than non-complaint homes. The analysis indicated that the complaint homes did not have a significantly higher level. Thus, use of complaint home data would not significantly overestimate the calculated in-home exposure levels.[66]

In addition, the tests run in the Franklin/Oak Ridge laboratories were not similar to "an unheated, unairconditioned home"; they were run indoors in heat controlled settings.[67] One must also find it unusual that the court, as a matter of law, concluded that the average house has air-conditioning and that the air-conditioning is used regularly.

In support of the decision to vacate the ban on installing UFFI in schools, one could reasonably rely on the *Texas Ginners* because CPSC did not have data demonstrating that use in schools was hazardous. However, under the *Reserve Mining* approach, the ban does not seem unreasonable since a sensitive segment of the general public would be at risk (i.e., children) and UFFI is known to cause acute irritant effects to approximately 20% of the healthy individuals exposed to levels typically encountered in the first 30 weeks after installation.[68] In addition, children living in UFFI homes and also attending UFFI schools would receive significantly higher doses than projected by the risk assessment. Thus, their risk would be substantially underestimated rather than overestimated as in the *Texas Ginner* case.[69]

Generally, it appears that exposure assessments must be supported by substantial evidence to pass judicial review. However, there appears to be an exception when reviewing uncertain exposures. If the public health is involved and a significant number of persons are potentially affected, courts are more likely to err on the side of safety and allow regulation. Where small discrete populations and significant expense are involved in regulating the potential exposure, courts tend to require more specific verified exposure analyses to justify regulatory action. The exposure analysis review in the *Foam Insulation Case* highlights an area which is likely to receive more attention in future cases; the reasonableness of the exposure scenario. Compounding conservative assumptions can easily result in the analysis overpredicting the likely exposure by a factor of a million. This does not imply that a "worst case" analysis is not acceptable; however, it should be a reasonable worst case.

DEMONSTRATING A RISK

After an exposure assessment is completed, the next step is to evaluate whether or not a significant risk is present. To demonstrate that a risk exists, the agency must have sufficient evidence to demonstrate that current or anticipated exposure levels pose an unreasonable risk. Such data may include health studies, epidemiological studies or animal studies. The demonstrated risk may be acute health effects, cancers or subchronic disorders to name a few.

Normally, the agency will be presented with numerous conflicting reports on the level and likelihood of harm caused by exposure to the toxicant(s) in question. The agency must determine from this

information whether or not the harm is significant and likely to occur given the circumstances of the exposure assessment. Courts tend to be rather deferential in this determination. The Supreme Court has stated that when available evidence of equivalent quality is conflicting, a finding in accordance with one view or the other should be considered to be supported by substantial evidence.[70]

Recent cases show a trend toward requiring an agency to demonstrate both qualitatively and quantitatively that a risk exists; a risk assessment analysis is almost a necessity for any agency wishing to defend new toxics regulations. In the *Benzene Case,* the Supreme Court stated that OSHA must prove a specific level of exposure "more likely than not" presents "a significant risk of material health impairment."[71] In the *Benzene Case,* OSHA did not present data that the current 10 ppm standard posed any health hazard. OSHA relied primarily on epidemiological data taken at much higher levels (estimated to be about 100 ppm) and the premise that no level of exposure was safe.[72] The Court rejected this as rulemaking based on assumption and stated that regulations "based only on inferences drawn from studies involving much higher exposure levels rather than on studies involving these levels or sound statistical projects from the high level studies"...are not adequate to demonstrate that a significant risk exists.[73] The Court also stated that the agency could base its determination of significant risk on animal studies conducted at higher levels if a dose response curve was generated.[74] Other courts have also held that extrapolation from animal data may be used to establish the probability of harm to man.[75]

When faced with uncertainty over the effects of a carcinogen at a specific level, agency action is not precluded if substantial evidence exists to demonstrate a risk. In the *Lead Case,* the court stated that "the Agency decision may be fully supportable if it is based on the inconclusive but suggestive results of numerous studies."[76] The court also went on to evaluate the Supreme Court's decision in the *Benzene Case.* It indicated that in the plurality's view, the OSHA standard "rested on rigid categorical assumptions about the health dangers of benzene, rather than specific evidence of its likely harm."[77] The *Benzene Case* also supports the D.C. Circuits' position that a precise correlation of exposure and effect is not necessary to revise an existing standard. However, the agency must present evidence "showing it is more likely than not that there is a significant risk" at the existing standard.[78]

The standard set in the *Lead Case,* unlike most other toxicant standards reviewed by the courts, was based on subclinical effects rather than the likelihood of cancer.[79] Protection from subclinical effects was also the basis for the standard set by OSHA in the *Cotton Dust Case*[80] that was sustained after Supreme Court review.[81] These cases demonstrate that non-cancer health impairments may also be considered significant risks.

A review of the scientific justification required by the Fifth Circuit to demonstrate that a significant cancer risk was present, indicates that the Fifth Circuit's decision is substantially at odds with prior Supreme Court decisions and those expressed by other Circuits. The court implied that CPSC's evidence of carcinogenicity was insufficient to demonstrate significant risk because, although animal studies produced nasal cancers, the human epidemiologic studies did not find a statistical increase in such cancers.[82] In addition, the court stated that a single animal study based on 1920 subjects (the court erroneously stated only 240 subjects were used) is insufficient to develop a dose response curve for formaldehyde.[83] These findings are contrary to scientific standards established by leading government cancer authorities and ignore the substantial body of evidence indicating that formaldehyde is carcinogenic.[84]

This outright substitution of judgment is also contrary to the Fifth Circuit's own language on the scope of judicial review of agency findings enunciated in *American Petroleum Institute v. OSHA.*[85]

As a parting blow, the court stated that using animal data to support a finding of unreasonable cancer risk is "of questionable validity" since the industry points out that "...it is far more sensible to assume that rats equal mice than that rats equal humans."[86]

If the court means to imply that human test data at current concentrations are necessary to substantiate a present health risk, one would have a difficult time finding support for this position in any Supreme Court or other circuit court decision.[87]

QUANTIFICATION OF RISK

To determine whether a demonstrated risk is significant, some quantification of risk is normally required. The Supreme Court's decision in the *Benzene Case* has generally been interpreted to imply that risks must be quantified and that incremental benefits of reducing exposure must be assessed.[88] This belief appears to result from the Court's directive that an agency must prove that a specific level of exposure "more likely than not" presents "a significant risk of material health impairment."[89] However, other language in the *Benzene Case* indicates that quantitative estimates are not required, especially "when at the frontiers of science."[90] Thus, the Court recognizes that situations will exist where a numerical risk analysis cannot be conducted with any substantial degree of reliability. In addition, the Court states, "although the agency has no duty to calculate the exact probability of harm, it does have an obligation to find that a significant risk is present before it can characterize a place of employment as unsafe."[91] Recent cases show, however, that quantifying the risk at the existing levels of exposure will increase the agency's chances of successfully defending its regulatory actions.

In the *Cotton Dust Case,* the risks of bysinossis from cotton dust were well established, and OSHA was able to construct a dose/response curve from epidemiological data. The agency analyzed the harm at current levels and also at the proposed permissible exposure limit (PEL). The rulemaking, as related to the new PEL, was upheld on all respects.[92] The *Lead Case* also demonstrates the D.C. Circuit's tendency to approve agency action when a quantification of the risk from exposure and improvement from reduced exposure has been conducted. The court noted that, unlike the *Benzene Case,* "OSHA was able to describe the actual harmful affects of lead on worker populations at both the current PEL and the new PEL" by using an air/blood level correlation.[93] It appears that an agency should quantify the risks and improvements associated with the rulemaking whenever possible.

When requiring a quantified risk, most courts appear to be referring to the existing condition as opposed to justifying the specific standard chosen below the unreasonable risk level. In the *Benzene Case,* the Supreme Court's major complaint with the OSHA analysis was that it assumed carcinogens should be reduced to the lowest extent feasible.[94] OSHA did not have any data demonstrating the presence of a risk at the current permissible exposure level (PEL). Without data verifying that the current PEL posed a risk, the agency should have developed a risk assessment model to translate the effects of high exposure levels to the existing low exposure levels. The Court points to numerous other OSHA actions where OSHA quantified the number of lives saved or cancers prevented as better examples of justified agency rulemaking.[95]

In the *Coke Ovens Case,* which followed the *Benzene Case,* the court did not require an estimate of cancer risks at levels below the old PEL.[96] In a rulemaking involving vinyl chloride, OSHA had animal test data at the current PEL of 50 ppm showing that 50% of the animals died after 11 months. This was considered evidence of a significant threat at the current exposure level, and the agency did not weigh the relative benefits of setting a new PEL other than 1 ppm. The primary consideration at this point was whether or not the proposed PEL was "feasible."[97]

Most courts have also taken the position that the final standard chosen by a regulatory body will not undergo the same rigorous review as the methodology to arrive at that standard. "Where the standard requires OSHA to set a numerical limit for some phenomenon we must remember that the precise choice of a number is essentially a 'legislative' judgment to which we must accord great deference and which only must fall within the 'zone of reasonableness'."[98]

These cases reflect the deference the Supreme Court typically accords agency decisions that attempt to quantify risks. "So long as [findings] are supported by a body of reputable scientific thought, the Agency is free to choose conservative assumptions in interpreting data with respect to carcinogens, risking error on the side of overprotection rather than underprotection."[99]

Thus, it is apparent from the case law that regulation based on a quantified risk analysis has a greater chance of passing judicial review than a qualitative risk analysis; however, quantitative analyses are not strictly required to pass judicial muster. In addition, the quantified risk analysis must demonstrate with substantial evidence that the existing standard or condition poses an unreasonable risk rather than that the proposed standard is the correct one.

In the *Foam Insulation Case,* the court took the general position on risk quantification that other courts have taken. They stated, "predicting how likely an injury is to occur, at least in general terms, is essential to a determination of whether a risk of injury is unreasonable."[100] The court also stated that it is necessary to quantify risks at the exposure level actually associated with the existing exposure. Beyond this point, the Fifth Circuit significantly departed from the other courts.

In the *Foam Insulation Case,* CPSC appeared to follow the directives laid down in the *Benzene Case* on quantifying risks; however, the court rejected the analysis. The CPSC used a risk analysis model to project the cancer risk posed by UFFI in houses. Unlike the *Benzene Case,* they had sufficient animal data at several doses and were able to construct a dose/response curve from that data. The CPSC risk analysis predicted that the cancer risk was 0 to 51 per 1,000,000.

Besides the data base issues previously discussed, the court stated that the estimates were insufficient because they were not precise.[101] However, the Supreme Court has specifically stated that "precise" estimates are not required.[102] The Fifth Circuit also indicated that the "margin of error is inherently large," and thus the analysis results were unreliable.[103] If the court means that uncertainty prevents CPSC from acting, this too has been specifically rejected by the Supreme Court.[104] The Fifth Circuit also implied that using the "upper level of risk" does not constitute substantial evidence that "it is more likely than not the UFFI presents a significant risk of cancer."[105] This line of reasoning has also been rejected by the Supreme Court since it has stated that the agencies may err on the side of overprotection.

Thus, based on a review of the existing case law, the Fifth Circuit has gone significantly beyond the level of detail and justification normally required to demonstrate substantial carcinogenic risks. Whether other jurisdictions are likely to follow this case remains uncertain.

HOW COURTS ARE LIKELY TO VIEW RISK ANALYSES PERFORMED UNDER SUPERFUND

The foregoing analysis of judicial decisions in the hazardous waste area indicates that substantial deference is normally accorded agency decisions to regulate those substances. And, as previously noted, the enabling statute plays a central role in determining how agency decisions should be reviewed. Considering the broad grant of powers established under CERCLA, it is difficult to argue that Congress intended CERCLA actions to be reviewed any more rigorously than other agency decisions in the hazardous waste field. However, unlike the other statutes relating to control of toxic substances, responsible parties under CERCLA are directly liable for costs incurred in abating a hazardous waste threat. For this reason, greater caution should be exercised by the courts before finding that a party is responsible and that all of the cleanup costs were necessary to abate the hazardous waste threat.

In most civil cases involving recovery of money damages, the burden of proof that a plaintiff must carry is a "preponderance of the evidence" (i.e., more likely than not). Although this burden of proof is essentially the same as the "substantial evidence/reasoned decision-making test" as applied to factual risk analysis decisions, in areas of uncertainty, judicial deference allowed under

this test clearly does not equate with the burdens of proof under the "preponderance of evidence" test. Thus, it is uncertain whether courts are likely to review Superfund risk analyses more closely. One could speculate that courts will still place a heavy burden on defendants because of the possible threat to public health that they have created and because Congress, by granting the USEPA board discretion under CERCLA, intended the courts to be deferential to USEPA decisions to respond to hazardous substance releases. In short, doubts concerning impacts on public health are likely to be resolved on the side of protecting public health.

CONCLUSIONS

Risk analyses, like other environmental effects analyses, are reviewed primarily under the substantial evidence/reasoned decision-making standard on the record. This has been interpreted to mean that the regulatory authority must demonstrate that the existing exposure it seeks to reduce more likely than not presents a significant health risk.

In reviewing the analyses used to demonstrate the human health or environmental risks, courts appear to be conducting more rigorous reviews than ever before. These reviews are tempered, however, by the statutory mandate under which the agency is acting and a respect for the limits of scientific capabilities. These two factors help the court to differentiate between factual decisions as opposed to legislative/policy decisions in the record. The latter are accorded greater deference (almost an arbitrary and capricious standard), and the former are reviewed more rigorously. Based on the case law reviewed a risk analysis will be capable of passing the substantial evidence/reasoned decision-making standard of review if the following steps are followed.

Date Base

- Courts recognize that conflicting information will often be encountered; thus, be certain to present an adequate analysis of why one set of data was chosen over another.
- Include a discussion of the quality of the data base and the ability to get "better" data (e.g., little help from industry being regulated).
- When a particular subset of data is used that could be considered biased or not representative, explain this choice.
- Indicate whether the data are likely to produce overestimates or underestimates.
- Where the data are admittedly "thin", explain the "policy" reason or scientific reason for using the data as a basis for regulation.

Model Selection

- Where no specific model best fits the data, explain why one model is chosen over another. If it is a policy reason (i.e., a conservative model to insure protection), state so explicitly.
- Review the model assumptions and determine whether they are reasonable for the current application.
- If certain factors are not accounted for in the model, explain why they are either not considered important or cannot be properly characterized at this time.
- State what assumptions in the model are not supported by the data and why the model is used in any event.

Exposure Assessment

- When choosing the routes of exposure, demonstrate the actual or likely existence of the route.
- If a previously undocumented exposure pathway is included or serves as the primary bases for a new analysis, explain the basis for the decision. This may be a legislative/policy rational, where substantial risk may be present and a large population potentially exposed but data do not substantiate that the pathway exists.
- Courts tend to view an exposure assessment as site specific. Only use an analysis from another situation where a new assessment is not feasible.

- When "transferring" an exposure analysis to another group, demonstrate significant similarities for level and duration of exposure, route of exposure and characteristic of substance.
- Indicate the confidence in the exposure estimate, if possible (i.e., is it likely to be an overestimate or underestimate?). Also discuss why more accurate assessments are not practicable.
- Where laboratory tests are used to simulate the rate of exposure, discuss differences/similarities between lab and actual conditions.
- Discuss how widespread exposure may be and whether it is a threat to the general public. This weighs in favor of taking action where precise exposures are less certain.

Demonstrating A Risk

- Present data or analyses that indicate current exposure levels pose an unreasonable risk.
- Where non-life threatening risks are protected, explain why.
- Animal tests should either be run at the current exposure level or be suitable for use in a risk assessment model.
- Indicate how the data are similar to the exposure situation.
- If the type of illness found in the animal data is not similar to any known human illness caused by the carcinogen, explain why this does not disqualify the data.
- Conduct an incremental quantitative evaluation of risk where possible.
- If above a certain number of cancers per 1,000,000 is considered an unreasonable risk, explain why. This may be a policy rationale.
- Where epidemiological studies are used to demonstrate risk, comment on their similarity to the present situation.
- Where a good correlation of exposure and effect cannot be made, explain why and whether or not more testing is desirable (i.e., why the agency believes enough evidence is present).

Quantification of Risk

- Demonstration of significant risk will usually require a quantification of risk.
- Although quantifying benefits obtained by reduced carcinogenic levels is not usually required, it is a good idea to include this analysis if possible.
- If present risks cannot be quantified, provide a detailed explanation of why, what would be needed to reliably conduct such an analysis and whether it is reasonable to wait for such an analysis.

Other Factors

- Wherever possible, indicate whether legislative/policy decisions or factual decisions are being made. Factual decisions generally require more supporting evidence.
- Where uncertainty exists, rely on legislative mandate in addition to other inferences that may be drawn from the data.
- Small incremental changes in existing carcinogenic standards are usually supportable only if a lower standard would have been implemented but technology prevented implementation of that limit.
- Avoid the Fifth Circuit if you are a regulatory body; this circuit clearly applies more stringent requirements than any other. If you are the consumer advocate, race to the D.C. Circuit.

REFERENCES

1. See Gough, *Laws for the Regulation of Carcinogens; Identifying and Estimating the Risks that the Laws Seek to Reduce, Toxic Substances J. 4,* 1983, 251.
2. 21 U.S.C. §348(c)(3)(A) (1976). More commonly known as the Delaney Clause.
3. 42 U.S.C. 9601 (1980).
4. In *U.S. V. Chem-Dyne* 572 F. Supp. 802,810 (1983), the court held that joint and severable liability applies under CERCLA unless the defendant demonstrates a reasonable basis for apportionment; *U.S. v. North Eastern Pharmaceutical & Chemical Co.,* No. 80-5066 CVSW-4 (W.D. Mo.) (1984), holding both the president and vice-president of NEPACCO, the sole generator, personally liable;

U.S. v. A & F Materials Co., No. 83-3123 (S.D. Ill.), (1984) holding that CERCLA could be applied to past non-negligent off-site generators.
5. Section 104(a)(1) of the Act authorizes the President to respond, consistent with the National Contingency Plan (NCP), whenever "any hazardous substance is released or there is a substantial threat of release into the environment." Section 105 of CERCLA states that the NCP shall include "methods and criteria for determining the appropriate extent of removal, remedy, and other measures authorized by this act." A review of the NCP indicates that many factors are considered in determining the appropriate extent of remedy; however, a "significant" threat must usually be present prior to initiating a federal response action. See NCP §300.68 and §300.65. Section 106 of CERCLA also allows the President to seek relief where an imminent and substantial endangerment is present. Such relief may take the form of administrative orders or injunctions where appropriate. Demonstrating a significant threat typically requires some form of risk analysis.
6. Section 107 of CERCLA requires that the cost removal or remedial action incurred by a Federal or State government be "not inconsistent with the national contingency plan" to be recovered from a responsible party. Considering the general nature of the NCP, it is not likely that many USEPA response actions will be found inconsistent with the NCP.
7. See Note 1 at 254-255.
8. 15 U.S.C. §§2051-2081 (1976).
9. 42 U.S.C. §§6901-6987 (1978).
10. 29 U.S.C. §§651-678 (1976).
11. 15 U.S.C. §§2601-2629 (1976 & Supp. v 1981).
12. See generally *Reserve Mining Co. et al. v. U.S.,* 514 F.2d 492 (8th Cir. 1975) (en banc); Merrill, *CPSC Regulation of Cancer Risks in Consumer Products: 1972-81,* 67 VA. L. Rev. 1261 (1981); Case, *Problems in Judicial Review Arising From the Use of Computer Models and Other Quantitative Methodologies in Environmental Decisionmaking,* 10 Boston Col. Envtl. Affairs L.R. 251 (1982); Substantive and Procedural Discretion in Administrative Resolution *Science Policy Questions: Regulating Carcinogens in EPA and OSHA,* 67 Georgetown L.J. 729 (1979).
13. Id, *Case* at 363.
14. Compare, *Industrial Union Dept, AFL-CIO v. American Petroleum Institute,* 448 U.S. 607 (1980) (the Benzene Case) with *Industrial Union Dept, AFL-CIO v. Hodgson,* 449 F.2d 467 (D.C. Cir. 1974) (the Asbestos Case). Also see generally *Amer. Textile Mfr.'s Instit. v. Donovan,* 452 U.S. 490 (1981) (the Cotton Dust Case) and *United Steelworkers of America, Etc. v. Marshall,* 647 F. 2d 1189 (D.C. Cir. 1980), cert. denied, 453 U.S. 913 (1981) (the Lead Case).
15. See Wallace, *Measuring Direct Individual Exposure to Toxic Substances, Toxic Substances J. 4,* 1983, 174.
16. In the 5th Circuit Review of the Benzene Case, *American Petroleum Instit. v. OSHA,* 581 F.2d at 507 (1978), the court indicates that dermal adsorbtion of benzene could have been verified by using a radioactive tracer test to check the rate of benzene adsorption and for this reason OSHA did not use the "best data available."
17. Latin, *The "Significance" of Toxic Health Risks: An Essay on Legal Decisionmaking Under Uncertainty,* 10 Ecology L.Q. 339 (1982); Rodgers, *Judicial Review of Risk Assessments: The Role of Decision Theory in Unscrambling the Benzene Decision,* 11 Envt'l L. 301 (1981); Ashford et al., *A Hard Look at Federal Regulation of Formaldehyde: A Departure From Reasoned Decisionmaking,* 7 Harv. Envt'l L.R. 297 (1983).
18. 701 F. 2d 1137 (5th Cir. 1983).
19. 449 F. 2d 467, 474 (D.C. Cir. 1974).
20. See *NRDC v EPA,* 655 F.2d at 328 (1981) and Note 14 *Ashford et al.*
21. In *American Paper Instit. v. EPA,* 540 F.2d at 1028 (10th Cir. 1976) the court stated that all issues should be viewed in light of the Congressional intent.
22. In *E.D.F. v Costle,* 578 F.2d 342-344 (D.C. Cir. 1978) the court relied heavily on the statutory language and legislative history to determine whether or not the EPA action was reasonable.
23. Clean Air Act, 42 U.S.C. §7412(b)(1)(B).

24. Resource Conservation and Recovery Act, 42 U.S.C. §§6922, 6924.

25. See Note 17, *Latin* at 395.

26. 452 U.S. at 494 (1981).

27. 701 F.2d at 1141 (1983).

28. *Vermont Yankee Corp. v. NRDC,* 435 U.S. 519 (1978).

29. 452 U.S. 490, 523 (1981).

30. *Industrial Union Dept., AFL-CIO v American Petroleum Instit.,* 448 U.S. at 653, n. 63 (1980).

31. See Note 17, *Ashford et al.* at 305.

32. 401 U.S. 402 (1971).

33. See Note 17 *Rodgers* at 305 and O'Malley, *American Petroleum Institute v Occupational Health and Safety Administration,* 581 F.2d 493 (5th Cir. 1978), 10 Env't'l L. at 673 (1980).

34. See Note 17, *Ashford et al.* at 365, n. 462.

35. *American Meat Institute v. EPA,* 526 F.2d at 457 (7th Cir. 1975).

36. 452 U.S. at 528 (1981).

37. *Weyerhauser Co. v. Costle,* 590 F. 2d 1011, 1054 (D.C. Cir. 1978). Also see *BSAF Wyandotte Corp. v. Costle,* 598 F.2d 637, 653 (1st Cir. 1979).

38. 701 F.2d at 1143 (1983).

39. *Id.* at 1145.

40. *Id.*

41. See Note 17, *Ashford et al.* at 363-368 for a review of these issues and the CPSC Petition for Rehearing filed May 5, 1983.

42. *United Steelworkers of America v. Marshall,* 647 F.2d at 1263 (1980).

43. See cases cited in Notes 35 and 37.

44. As stated earlier, courts tend to separate agency decisions into those that are factual and those that are legislative/policy in nature. Where a science/policy decision is made due to insufficient data, courts do not tend to question the expert agency decision.

45. 598 F.2d at 655 (1979). The work of Mr. Case (See Footnote 12) also corroborates that courts give great deference in reviewing decisions on selection of mathematical models or statistical techniques.

46. 499 F.2d 474, n. 18 (1974).

47. 701 F.2d at 1147, n. 20 (1983).

48. *Id.* at 1141.

49. *Id.* at 1146.

50. *American Iron and Steel Inst. v. OSHA,* 577 F.2d 825, 832 (3rd Cir. 1978).

51. *National Lime Association v EPA,* 627 F.2d at 452-53 (D.C. Cir. 1980).

52. 448 U.S. at 661 (1980).

53. *Id.* at 662.

54. 581 F.2d at 506 (1978).

55. 630 F.2d 398 (5th Cir. 1980).

56. *Id.* at 409.

57. In the technology transfer cases, the USEPA was attempting to use analyses developed for one type of industrial process as a basis for establishing an effluent guideline for other industrial processes where insufficient data prevented the Agency from developing a separate guideline.

58. See generally, *C & H Sugar Co. v EPA,* 553 F.2d 280 (2nd Cir. 1977).

59. See generally, 514 F.2d 492 (1975) (en banc).

60. *Id.* at 516-517.

61. *Id.* at 520.

62. 501 F.2d at 1148 (1983).

63. *Id.* at 1143. The court believed that complaint homes exhibited higher formaldehyde levels than non-complaint homes.

64. *Id.* at 1145.

65. *Id.* at 1149.

66. See Note 41.

67. *Id.*

68. 701 F.2d at 1148 (1983).

69. See Note 55.

70. *Universal Camera Corpl v. NLRB,* 340 U.S. 474, 478 (1951).

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72. *Id.* at 614.

73. *Id.* at 614.

74. *Id.* at 632, n. 33.

75. *Dry Color Mfrs. Assn., Inc. v. Dept. of Labor,* 486 F.2d 98, 104 (3rd Cir. 1973); *EDF v. EPA,* 548 F.2d 998 (D.C. Cir. 1976).

76. 647 F.2d at 1253, n. 46 (1980).

77. *Id.* at 1146.

78. 448 U.S. at 647, n. 64 (1980).

79. 647 F.2d at 1252 (1980).

80. 617 F.2d at 654, 655.

81. 452 U.S. 490 (1981).

82. 701 F.2d at 1145 (1983).

83. *Id.* at 1147, 1147.

84. See generally, Note 8, *Ashford et al.*

85. 581 F.2d at 507 (1978).

86. 701 F.2d at 1147, n. 20 (1983).

87. See Note 71 and 448 U.S. at 657, n. 64 (1980).

88. See generally, Note 14.

89. See Note 69.

90. 448 U.S. at 656 (1980).

91. *Id.* at 655.

92. See generally, 452 U.S. 490 (1981).

93. 647 F.2d at 1248 (1980).

94. 448 U.S. 652, n. 60 (1980).

95. *Id.*

96. *American Iron and Steel Inst. v. OSHA,* 577 F.2d 825 (3rd Cir. 1978).

97. 39 *Federal Register* 35890, 35891.

98. 647 F.2d at 1253 (1980).

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100. 701 F.2d at 1148 (1983).

101. *Id.* at 1146.

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PRACTICAL USE OF RISK ASSESSMENT IN THE SELECTION OF A REMEDIAL ALTERNATIVE

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INTRODUCTION

The majority of a National Priority Listed (NPL) hazardous waste sites require the completion of a remedial investigation/ feasibility study (RI/FS) as a basis for subsequent site cleanup. Characterization studies have been completed for several NPL sites in sufficient detail to serve as a basis for subsequent evaluation and selection of a cleanup alternative. Other sites may require an RI to generate the necessary data required for the final selection of a remedial alternative. The Feasibility study remedial alternative evaluation process which includes a risk assessment is the focus of this paper.

Selection of an appropriate remedial alternative for a hazardous waste site ideally rests on a detailed risk assessment and on a careful analysis of the relative impact of each alternative on public health, welfare and the environment. In practice, limited data and time often place serious constraints on the depth of the assessment, yet the need for a defensible selection of a remedial action remains.

Concentrating on public health impact, the authors discuss Metcalf & Eddy's approach of focusing on the scope of a risk assessment while generating information necessary to make a defensible selection of a remedial alternative. The approach includes initial screening of contaminants to select those most important for assessment, simplified models for estimating exposure and use of matrices to assure consistant consideration of all risk assessment criteria in the selection of a final remedial alternative.

RISK ASSESSMENT

In recent years, several scientific papers have been published on the appropriate methodology to be used for evaluating the public health risks posed by uncontrolled hazardous waste sites. While most authors discuss the need to evaluate the various chemical, physical, biological and toxicological properties that affect exposures and ultimately risks, few writers point out the major time and data limitations imposed upon most risk assessments of hazardous waste sites. Detailed evaluations are often not possible and for many sites may not be necessary to select a remedial alternative.

To complete a study within a short time frame, the major risks must be identified rapidly to screen out remedial actions that are unwarranted and to focus on those that are most likely to effectively mitigate possible impacts on public health. This approach requires:
- Selecting the major contaminants of concern for the site
- Using simple exposure "models" or estimates to screen out remedial actions that are unnecessary

- Ranking the remaining alternatives according to their relative impact on public health

Although this approach discussed below focuses on public health impact, the same methodology may be applied to the study of the other criteria used in the selection of a remedial alternative.

Selection of Target Compounds for Assessment

A typical uncontrolled hazardous waste site, particularly one that is early or pre-superfund, is the analyst's nightmare. It is likely to contain over 100 different compounds identified over the years by several investigators whose analytical techniques and objectives differed. Characterization of the nature and extent of site contamination is therefore often sketchy.

The first step in conducting a "focused" risk assessment is to select a limited group of compounds for evaluation. This step may be accomplished relatively quickly by ranking the compounds identified on-site by extent of contamination and toxicity with inclusion of major factors that influence their transport in the air, water or soil. This selection process should be carried out for each potential route of exposure in order to select those 10-15 compounds that are of concern for each transport medium.

Often, the absence of sufficient toxicologic or epidemiologic data will preclude evaluation of certain compounds from the outset. The National Research Council recently estimated that only 21% of all of the chemicals used in commerce (excluding drugs, pond additives and pesticides) have even minimal toxicity information. Data on subchronic, chronic and reproductive effects is particularly lacking (3-10%).[1]

Screening Remedial Actions

Once the compounds have been selected for analysis, the next step is to evaluate the relative level of risk for each route of exposure. The objective of this assessment is to establish the relative importance of each route of exposure to eliminate or minimize further analysis of routes that have little impact.

The relative, rather than absolute or "true", impact is the objective of the analysis because the limitations typically imposed on studies of this kind currently make estimates of the absolute risks difficult if not impossible. The large uncertainties in both the conceptual models and the data necessary to run them plague both exposure and risk estimation steps. For instance, there is a growing consensus in the scientific community that the apparent need for groundwater modeling to study contaminant migration has generally outstripped the development of the necessary models and data.[3, 4] Even with the best of data, the ability of groundwater

modeling to predict the levels of contaminants at any given location or time is relatively poor.[5] Similarly, models used to extrapolate results of toxicity testing in animals at high doses to effects of human exposure to low doses, while useful, are still largely unproven. The cumulative effect of these uncertainties is to obscure any statistical distinction between mean or best estimates of risk.

A more suitable approach for the typical feasibility study is to use simple models to screen the relative importance of various routes of exposure under worst case conditions. Remedial actions involving routes of exposure that can be shown to be of little importance may often be eliminated from detailed evaluation. A recent feasibility study conducted by M&E of an uncontrolled waste site, the ABM Wade Property in Chester, Pennsylvania (Wade Site), illustrates the usefulness of "screening" level models.

Wade Disposal Site

The Wade Site covers three acres on the banks of the Delaware River in Chester. Originally a rubber reclamation facility, the site was used as an industrial waste storage and disposal facility in the early 1970s. More than 4,000 drums of toxic industrial waste were stored on the property or had their contents poured directly into the ground. Thousands of gallons of waste were discharged directly from tank trailers onto the ground.

At the time of the study, the USEPA and the Pennsylvania Department of Environmental Resources (DER) had conducted a partial cleanup of the site to remove remaining barrels and trailers of waste. A previous contractor had identified several potential remedial alternatives prior to any risk assessment of the site.[5] Of particular concern were the evaluation of the need for a slurry wall and leachate collection system and the selection among several detailed soil removal options. The site was known to be a playground for local neighborhood children.

To evaluate the potential impact of contaminated leachate on the Delaware River and of contaminated soil on children playing on the site, Metcalf & Eddy investigated five routes of exposure:
- Ingestion of drinking water from the Delaware River
- Ingestion of contaminated fish from the Delaware River
- Inhalation ingestion of contaminated dust from the site
- Ingestion of contaminated soil
- Inhalation of volatile contaminants emitted from the site

The evaluation process focused on the cancer risks because of the increased risks statistically associated with even low levels of exposure. All risks were calculated using unit risk factors (mg/kg/day)$^{-1}$ developed by the USEPA Carcinogen Assessment Group.[7]

To estimate the maximum level of contamination of the Delaware River resulting from groundwater discharges from the Wade Site, several worst case assumptions were used. First, the peak contaminant concentrations detected in groundwater on-site were assumed to be representative of groundwater quality throughout the site. The maximum estimated flow of groundwater contaminated at these levels was assumed to discharge into the Delaware River daily and to mix completely within one half of the total flow. The calculations also assumed no loss of contaminants through attenuation in soils, biodegradation or any other mechanism.

The results of this analysis for a few compounds detected in highest quantities at the site are shown in Table 1. The calculations indicate that, even under the gross assumptions made, the final concentrations of these chemicals in the Delaware River were likely to be well below applicable drinking water criteria.

Ingestion of contaminated fish was also a major concern because of bioaccumulation potential of the major Wade site contaminants and the observation of persons fishing from the Wade property. To estimate the concentration of contaminants expected in fish, steady-state bioaccumulation factors obtained from the available literature were applied to the concentrations of contaminants in the Delaware River calculated earlier. Increased lifetime cancer risks from eating 6.5 g of contaminated fish were then estimated.[9]

The results of this analysis for benzene, dichlorobenzenes and trichloroethylene which were all found in high concentrations in groundwater are shown in Table 2. Despite bioaccumulation in fish

tissues, the contaminants were unlikely to pose serious increased lifetime risks of cancer.

Comparison of risks associated with contamination of the Delaware River with risks posed by more direct contact with contaminated soils suggest that the latter is potentially a more important route of exposure. Three routes of exposure to contaminants on-site were evaluated; inhalation of contaminated dust (generated during on-site activity), direct ingestion of contaminated soil (i.e., by a young child) and inhalation of organic vapors emitted from remaining on-site waste.

Table 1
Impact of Wade Site on Delaware River Water Quality

Compound	Groundwater Concentration ug/l	Concentration in Delaware River (1/2 flow)[1] ug/l	Human Health[2] Criteria ug/l
Benzene	3,100	0.006	0.066[3]
Dichlorobenzene	670	0.001	400.00
1,2 Dichloroethane	6,500	0.013	0.94[3]
1,2 Dichloropropane	7,050	0.015	
Toluene	12,400	0.026	14,300
1,1,1 Trichloroethane	21,600	0.004	1,000
Trichloroethylene	5,300	0.011	2.7[3]
Metals			
Chromium	1,210	0.002	50.0[4]
Lead	2,530	0.005	50.0[4]

(1) Equation used:

$$C_{GM} + C_{DR} = \frac{(C_{GM} + Q_{GM} + C_{DR} + Q_{DR})}{Q_{GM} + Q_{DR}} (0.5)$$

where:

Q_{GM} = 0.01 mgd (maximum groundwater flux through Wade Site)

Q_{DR} = 9,695 mgd (full flow of Delaware River)

C_{GM} = Concentration in groundwater

C_{DR} = Data for ambient concentrations in Delaware River assumed to be zero

(2) *Federal Register* 45(231): 79318-79379 Water Quality Criteria Documents

(3) *Ibid.*, 10-6 Cancer Risk level associated with ingestion of 2 l of water and 6.5 g of fish per day.

(4) National Interim Primary Drinking Water Regulations

For each scenario, worst case assumptions were made. To estimate the possible exposure from inhalation of contaminated dust, airborne dust concentrations of 10 mg/m^3 (the American Conference of Governmental Industrial Hygienists Threshold Limit Values for nuisance dust) were assumed for an 8 hr exposure. Assuming a breathing rate of 1 m^3/hour, 100% impaction of dust in the respiratory system and 100% absorption of the contaminant, a dose (mg/kg/day) to an individual (70 kg) could be estimated for each peak concentration of contaminants. For a small child (20 kg), the dose from ingesting contaminated soil depended on intake of 1 g of soil per day[8] and an assumption of 100% absorption into the body. Doses were then multiplied by carcinogenic unit risk factors (mg/kg/day^{-1})[7]. The cancer risks associated with inhalation ingestion of soil with those associated with ingestion of contaminated fish are compared in Table 2. The risks posed by the soil exposure route are, in general, several orders of magnitude greater than those from contaminated soil.

On the basis of these results, the proposed slurry wall, leachate collection and treatment system were eliminated from further discussion. The feasibility study was instead focused on remedial alternatives that reduced or eliminated exposures to soil.

Table 2
Increased Lifetime Cancer Risks

	Compounds[1]	Cancer Risk[2]	Major Assumptions[3]
Ingestion of Delaware Fish (Adult)	benzene trichloroethylene dichlorobenzene	9.6×10^{-7} 1.4×10^{-10} 9.0×10^{-9}	Dilution in 1/2 flow of Delaware Steady State Bioconcentration 6.5 fish/day 70 kg adult 100% absorption into body
Inhalation of Contaminated Soil (Adult)	1,2 dichlorobenzene di (2 ethylhexyl phthalate)	2.4×10^{-4} 2.9×10^{-5}	Dusty conditions - 10 mg/m³ 1m³ breathed/hour 8 hour exposure 70 kg adult 100% absorption into body
Ingestion of Contaminated Soil (Child)	1,2 dichlorobenzene di (2 ethylhexyl phthalate)	8.3×10^{-2} 1.3×10^{-3}	1000 mg ingested per day 20 kg child 100% absorbtion into body
Inhalation of Volatile Compounds (Adult)	benzene trichloroethylene	7.3×10^{-5} 2.2×10^{-5}	8m³ breathed/day 70 kg adult 100% absorption through lungs

(1) These compounds were found in highest concentrations in each medium and are assumed to be representations of concerns throughout the site.

(2) Risk = Increased lifetime risk of cancer. All cancer risks calculated using unit risk factors developed by the USEPA Carcinogen Assessment Group.

(3) These assumptions are intended to result in calculations of worst case risks.

Ranking of Remedial Alternatives; A Matrix Approach

Use of screening models may be of little help when the remedial alternatives are relatively similar. The uncertainties inherent in the risk assessment process are likely to obscure distinctions among the alternatives. In such cases, ranking remedial alternatives with the help of a matrix may be simpler, faster and equally justifiable.

The objective of the matrix is to ensure that all of the factors affecting a decision are explicitly integrated into the selection process. The alternatives fall along the vertical axis and the decision factors along the other. Each alternative is ranked relative to the others for each decision factor, total scores are tallied and final rankings are established. The rankings are not intended to reflect the absolute differences between the impacts of the various alternatives (e.g., that one alternative is three times worse than another). Rather, they reflect professional judgment of the relative impact of the various alternatives.

The Wade Site again serves as an example. Twelve distinct remedial alternatives were developed by a previous contractor. They involved various combinations of two capping alternatives with three soil removal options. The soil removal options involved excavation to various depths dependent on "action levels" set for total levels of contaminants in soils. The action levels were not based on rigorous public health considerations.

Selection of any alternative required an implicit trade-off between the potential for increased short-term exposure to compounds in air during soil removal and the longer term benefits of removal of the more contaminated soils from the site. Rather than attempting to model the potential exposures associated with each of the remedial alternatives, a matrix was used.

The matrix used to rank the Wade Site alternatives by public health impact is shown in Figure 1. Only five of the original 13 alternatives are presented here and, of these, the soil removal Option 1 represents minimal soil excavation and Option 2 represents maximum excavation of soil. Decision factors ranged from physical safety hazards and potential exposures during remedial activities to possible occupational exposures during future development of the site. The final rating of the "effectiveness" of the alternative at mitigating public health impact appears in the final column.

The analysis suggested that an alternative requiring a moderate level of soil removal was ranked more effective in mitigating impacts on public health than both no soil removal and extensive soil removal options.

Analysis of the sensitivity of the matrix results to assumptions made in ranking the alternatives is an important final step. The matrix implicitly gives equal weight or importance to each decision factor despite the likelihood that certain decision factors may be considered to be more important than others or that the analyst may have more confidence in the ranking of alternatives for certain decision factors. Sensitivity analysis permits evaluation of the effect of according different weight or importance to certain decision factors on the final ranking of alternatives. It also helps to reveal if the analyst's bias toward a given alternative has skewed the results.

For the Wade Site, a sensitivity analysis was conducted by according greater weights first to decision factors related to short term or acute hazards and secondly to longer term or chronic hazards and noting the effect on the final ranking. Although not shown here, changing the weighting factors had little effect on the final order of alternatives, thus indicating that the result was reasonably robust.

A final ranking of alternatives that is highly sensitive to variations in weighting factors should not be considered a defect for the analyst. It may simply indicate what is often suggested from the outset—that a clear choice among remedial alternatives does not exist.

As mentioned earlier, the approach of first screening and then ranking remedial alternatives can be used to evaluate alternatives on the basis of the other "effectiveness" criteria that must be considered in making a final selection under the National Contingency Plan. The following section discusses the incorporation of results of the individual effectiveness criteria evaluations into a comprehensive matrix for selection of the final alternative.

FINAL SELECTION OF A REMEDIAL ALTERNATIVE

Selection of a cost-effective remedial alternative must be based on other "effectiveness" and cost criteria in addition to the public health risks. These criteria include environmental risks, institutional issues, implementability/reliability issues, construction/implementation costs and post closure, long-term monitoring and maintenance costs.

M&E has adopted and modified an approach for evaluating effectiveness and cost issues for remedial alternatives based on a Methodology Manual prepared for the USEPA[10] and a USEPA Guidance Document.[11] M&E's focused approach is based on the following principal components:
•Reliance exclusively on data generated during previous investigations of the site
•Qualitative effectiveness criteria assessment and quantitative cost criteria assessment
•Use of matrices for criteria and alternative assessment
•Use of a matrix as a basis for selection of a cost-effective remedial alternative

Metcalf & Eddy's approach to evaluating the cost-effectiveness of remedial alternatives in a focused, timely manner is highly dependent on the four principal components previously listed. The following brief discussion will describe in more detail these components and how they have been applied to the Wade Site as previously described.

Generally, a focused feasibility study is conducted for a site where prior studies have provided sufficient data for the evaluation of remedial alternatives. The Wade Site had approximately 40 reports or other file documents available for the feasibility study. All 40 documents were arranged chronologically and evaluated by the study team for applicability to the effectiveness and cost criteria.

Even after evaluating all existing data, several assumptions may be necessary to complete a focused feasibility study. Each assumption must be valid, realistic, applicable and serve to focus the remedial alternative selection process for the particular site. The objective in stating any assumption is twofold: (1) to reduce any necessary assessment of site data and (2) to provide the necessary data for input into the alternative selection matrix.

*Effectiveness ratings were ranked in reverse of public health impacts
10 (most effective) - 1 (least effective)

Figure 1
Public Health Risk Assessment-Wade Site-Chester, Pennsylvania

REMEDIAL ALTERNATIVES	Public Health Impact due to:	Physical Safety Hazards	Volatile Chemicals (VOC): offsite population, remedial phase	VOC: Airborne Exposure to Population, Post Closure	(VOC): Airborne exposure to remedial phase	(VOC): Airborne exposure post closure	Chemicals, Skin Contact to children on site. Remedial Phase	Chemicals, Skin Contact to children on site. Post Closure	Chemicals, Skin Contact to Children remedial phase	Chemicals, Skin Contact to Children post closure	Chemicals, inhalation of particulate.	Chemicals, inhalation of particulate.	Exposure to offsite population during truck	TOTAL	EFFECTIVENESS RATINGS*
NO ACTION	10	10	4	4	6	8	10	8	10	10	0	4	0	82	5
REMOVE ON-SITE WASTE GRADE PROPERTY	2	2	5	3	7	6	8	8	8	8	2	2	2	65	6
REMOVE ON-SITE WASTE SITE CAP	2	2	5	1	7	1	8	3	8	3	2	2	2	46	8
REMOVE ON-SITE WASTE EXCAVATE SOIL OPTION 1	2	2	10	1	10	1	7	1	7	1	2	2	8	52	7
REMOVE ON-SITE WASTE EXCAVATE SOIL OPTION 2	2	2	6	1	8	1	4	2	4	2	2	2	3	39	10

Effectiveness criteria assessments are generally conducted on a qualitative basis, whereas cost criteria assessments are quantitative. Effectiveness criteria include environmental, institutional and implementability which are all assessments used in the ranking of various proposed remedial alternatives relative to one another. For most sites, including the Wade Site, quantitative distinctions often cannot be made on the basis of available site data.

Evaluation of remedial alternatives on the basis of institutional issues (permit requirements, community relations, etc.) may also be handled on a qualitative basis for studies completed in a short time frame. For example, at the Wade Site, those remedial alternatives involving off-site transport and disposal of hazardous wastes may result in greater institutional impacts due to permitting requirements and lesser impacts in terms of a community relations program.

Assessment of remedial alternatives based on implementability/reliability issues is also qualitative but is based on a variety of factors including the durability of the alternative, ease of installation and the time needed for cleanup. Engineering judgment regarding proven remedial alternative technologies is critical to this successful assessment. For example, the site capping/waste removal as proposed for the Wade Site made greater use of proven technologies than those minimal cleanup alternatives and, therefore, were rated as more highly reliable.

Cost criteria assessment should be handled in a quantitative rather than qualitative manner. Present worth implementation costs for proposed remedial alternatives may be calculated based on standard cost estimating procedures. Post closure, long-term monitoring costs for each alternative can also be quantified based on certain site specific assumptions. Quantitative cost criteria assessment for the Wade Site indicated important differences in overall alternative costs which may have been difficult to determine if this assessment had been performed on a qualitative basis.

It is important that each assessment of individual effectiveness criteria was performed by a different professional as part of a multi-disciplinary evaluation team. All members of the team were brought together to develop the final remedial alternative selection matrix only after completion of the individual assessments of the various effectiveness criteria. This procedure helped to eliminate any bias toward any one particular remedial alternative in advance of the preparation of the final selection matrix.

FINAL REMEDIAL ALTERNATIVE SELECTION: USE OF A MATRIX

A schematic of a matrix used in the Wade Site alternative selection process is shown in Figure 2. Effectiveness and cost criteria are listed across the top while the alternatives are listed along the side.

This comprehensive matrix integrates cost with assessments of the effectiveness criteria (public health, environment, institutional, technical) for each alternative to aid in the selection of the most cost-effective remedial alternative consistent with the objectives of the National Contingency Plan. For each alternative, final effectiveness and effectiveness/cost ratings have been developed and are presented in the last two columns of the matrix. Final effectiveness ratings are calculated by multiplying the weights accorded a given effectiveness measure by the individual effectiveness ratings given for each criterion. Final cost ratings are calculated by multiplying the sum of the implementation and monitoring costs by the weighting factor. The effectiveness/cost rating for each remedial alternative is the division of the two separate ratings discussed above. A higher relative rating indicates that a particular alternative is more cost-effective.

The weighting factors, which appear in the top row of the matrix, reflect the relative priority given to each effectiveness measure and to costs. The relative priorities should be established in advance by the lead agency for the site. These weighting factors are important determinants of the overall results of the cost-effective matrix analysis. The sensitivity of this analysis may be determined by changes in the assignment of weighting factors to each effectiveness or cost criterion. The matrix easily permits this kind of sensitivity analysis.

Figure 2 is part of the Wade Site Remedial Alternative Cost-Effectiveness Matrix. The weighting factors, which appear in the top row of the matrix, reflect the relative priority given to each effectiveness measure and cost by the USEPA's Office of Waste Programs Enforcement. Highest priority is given to public health followed by the protection of the environment, implementability

Figure 2 — Remedial Alternative Cost-Effectiveness Matrix, Wade Site-Chester, Pennsylvania

REMEDIAL ALTERNATIVES	Construction Costs	Post Closure, Long-Term Monitoring and Maintenance Costs	% Cost Ratings	Public Health Risks	Environmental Risks	Institutional Issues	Implementability/Reliability Issues	% Effectiveness Ratings	% Effectiveness Ratings / % Cost Ratings
WEIGHTING FACTORS	1	1		5	4	2	3		
1. NO ACTION	0.000 / 0.000	0.305 / 0.305	0.305	5 / 25	2 / 8	5 / 10	4 / 12	55	180
2. REMOVE ON-SITE WASTE GRADE PROPERTY	0.798 / 0.798	0.366 / 0.366	1.164	6 / 30	3 / 12	5 / 10	4 / 12	64	55
3. REMOVE ON-SITE WASTE SITE CAP	1.130 / 1.130	0.316 / 0.316	1.446	8 / 40	4 / 16	6 / 12	2 / 6	74	51
4. REMOVE ON-SITE WASTE EXCAVATE SOIL-OPTION 1 SITE CAP	3.084 / 3.084	0.316 / 0.316	3.400	7 / 35	10 / 40	10 / 20	4 / 12	107	31
5. REMOVE ON-SITE WASTE EXCAVATE SOIL-OPTION 2 SITE CAP	1.580 / 1.580	0.318 / 0.318	1.898	10 / 50	5 / 20	7 / 14	10 / 30	114	60

Figure 2
Remedial Alternative Cost-Effectiveness Matrix, Wade Site-Chester, Pennsylvania

and reliability of the alternative institutional issues and finally cost.

The NCP dictates that the remedial alternative should be selected on the basis of both cost-effectiveness and the environment. In part, the NCP states that selection of a remedial alternative should be based on: "the lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of Public Health, Welfare, and the Environment."[12]

On this basis, the no-action alternative was eliminated. Although it has a high "effectiveness cost" rating (a function of the small cost of doing nothing to change existing site conditions), it was rated lowest in terms of effectiveness and, therefore, was not considered further. The non-soil removal alternatives (2 and 3) were also eliminated using the same reasoning.

The remaining contaminated soil, removal alternatives (4 and 5) have the highest "effectiveness" ratings, the most "effective" of these being alternative 5. This also had the highest effectiveness/cost rating of the soil-removal options and, on this basis, was recommended to the USEPA for selection as the most cost-effective remedial alternative for the Wade Site.

CONCLUSIONS

Simple models and decision matrices can often be useful tools for evaluating and organizing the complex conditions often found at uncontrolled hazardous waste sites. They can assist in the selection of a cost-effective remedial alternative within the data and time constraints typically placed on feasibility studies.

The public health assessment of remedial alternatives for the Wade Site in Chester, Pennsylvania illustrates the potential strength of simple, worst case models. Prediction of the impact of contaminated groundwater on the Delaware River depended not on a detailed, time-consuming evaluation of the various geological, chemical and biological factors affecting pollutant transport in groundwater, but on rapid simple estimates of flow through the site into the river. In this case, a more detailed evaluation was unwarranted. The simple estimates that were made permitted the elimination of a complex leachate collection and treatment system from further consideration.

Decision matrices help formalize the decision-making process. They are intended to assure that all of the factors affecting the selection of a remedial alternative are integrated into the evaluation. Matrices are therefore useful at each stage in the selection process from evaluation of alternatives according to each "effec-

tiveness" criterion to selection of a final cost-effective remedial alternative.

As any other tools, simple screening models and decision matrices have their limitations; they may not be appropriate for all situations, nor will they always lead to a clear choice of a remedial alternative. However, by helping to limit the number alternatives and to consistently consider all factors affecting a decision, they help assure a more defensible selection.

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CLEANUP COST ALLOCATION (CCA) MODEL

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INTRODUCTION

There are two major issues to be settled at most Superfund sites and at any waste cleanup scene where more than one party is involved: (1) agreement with regulatory officials as to the cleanup response required and (2) agreement among involved industries as to the apportionment of cleanup costs. The former issue has been given much attention and while difficult to address, has been subject to rational technical analyses. The latter issue is quite different and typically has not been approached in a rational or consistent manner.

In this paper, the authors present a cost apportionment mechanism which has been applied to a major Superfund site and is being considered for use at others. The mechanism is termed the Cleanup Cost Allocation (CCA) Model.[1,2] Development of the model began in January, 1983, when one potentially responsible party (PRP) involved in the PetroProcessors, Inc. (PPI) abandoned waste site near Baton Rouge, Louisiana took exception to its proposed "fair-share" of cleanup costs.

The authors were retained by this industry to develop a rational cleanup cost allocation model which could be applied to essentially any waste site. The model was applied to the PPI site from May through November, 1983.[3]

NEED FOR THE MODEL

The model was developed to fit the perceived need to account for substantial differences in the nature of wastes. The following example underscores the urgency for the acceptance of a waste-related apportionment scheme for allocating cleanup cost. Consider a site (with $10 million cleanup costs) consisting of 100,000 tons of relatively innocuous products from 20 generators and 1000 tons of known carcinogenic waste from a 21st generator. On a strict volume basis, the toxic waste generator would pay only $100,000. More realistically, however, the first 20 generators should pay the cost equivalent of having to close a solid waste landfill with all remaining costs being picked up by the toxic waste generator.

Currently, neither government nor industry has formal guidelines for handling cleanup cost allocation. Indeed, the issue of joint and several liability precludes government commitment to such guidelines. Without an organized approach toward accounting for waste properties and tendencies, cleanup costs for abandoned waste sites would be allocated among responsible parties based on volume alone, depth-of-pocket or at best those two factors would be considered along with an unorganized estimate of harm done.

CONSIDERATIONS FOR COST APPORTIONMENT

Thus, it was clear from the beginning that the model must incorporate waste-related factors impacting cleanup cost. Here, it is important to differentiate between the factors which impact the cost to cleanup a waste site and the factors which serve as a reasonable basis for cost apportionment among involved parties. Principal determinants of a waste site cleanup effort are listed below:
- Nature and quantity of wastes
- Site conditions (e.g., topography, geology, hydrology and climatology)
- Disposition of wastes (co-mingled, distinctly separate or a combination of the two)
- Interaction of wastes with site (surface water, soils/rock, groundwater, air and living environment) and with other wastes
- Criteria for cleanup (e.g., regulatory requirements and allowable residual contaminant levels)
- Closure and post-closure response adopted
- Public interest

Each of the above items impacts the cost to clean up a waste site. However, the only reasonable differentiating variable for apportioning cost among involved parties is the waste itself. A given set of wastes deposited in a clay environment versus a sandy environment will, other things being equal, require less expense to clean up. However, apportionment of the cleanup cost in either case should be according to the wastes involved—regardless of the total costs.

What are the waste factors that most significantly impact the cost of cleanup and how should they be weighted? The CCA model was developed to answer these questions.

MODEL DESCRIPTION

Basically, the CCA model is a mechanism for equitable allocation of "site" cleanup costs. Equitable cost allocation is defined as apportionment of cleanup expense among involved parties according to the impact their wastes have on total cleanup cost. Considerations for the model included: prior cleanup cost allocation efforts; existing hazard ranking systems; available cleanup cost information for on-site and off-site disposal and treatment; and cleanup methodology requirements.

The model is based on three fundamental criteria: (1) different wastes can pose substantially different risks to human health and the environment, (2) cleanup methodology and costs reflect concern for—and characteristics of—the wastes involved and (3) waste site cleanup typically involves not only the waste itself but also off-site contaminant migration.

"Site" is defined in the basic model as the land area physically used for treatment, storage and/or disposal of wastes, plus an arbitrary 100 ft lateral buffer zone (beyond the limits of the waste management land area) and a 10 ft vertical buffer zone (below the base of waste units). The inclusion of lateral and vertical buffer zones is a subjective and conservative effort to accommodate ill-defined waste deposition areas. However, "off-site" cleanup costs for highly mobile waste materials are still segregated from the less mobile wastes. Those highly mobile wastes will require separate cleanup cost apportionment incorporating site-specific data.

MODEL CONSTRUCTION

The CCA model rationale incorporates apportionment of cleanup costs according to assignments given to weighting factors for individual wastes. These factors comprise three major components listed below: (1) waste quantity, (2) biological (toxic) factors and (3) physical factors:

- Waste Quantity
- Biological (Toxic) Factors
  Acute toxicity
  Carcinogenicity
  Mutagenicity
  Teratogenicity
  Reproduction
  Subchronic and other toxic effects
- Physical Factors
  Consistency
  Mobility
  Activity
  Persistence
  Ignitability
  Corrosivity
  Reactivity

Scores are assigned to the above factors for each waste. Scoring follows rigorous compilation and evaluation of waste-related data. The individual waste cleanup cost allocation factors are then computed as follows:

Individual Waste Cleanup Cost Allocation Factor =

$$(A x B x C)/B(A x B x C),\qquad(1)$$

Where for any given waste:

A = Waste quantity (common units for all wastes)
B = Highest score assigned to the array of Biological Factors
C = Sum total of scores assigned to the array of Physical Factors

The cleanup cost allocation factor for each party is then the sum of its individual waste cleanup cost allocation factors.

It is important to recognize that: (1) the standard definitions of toxicity do not allow sufficient discrimination to truly evaluate toxicity as a cost impact factor and arbitrary scoring systems have to be established; (2) the probability that certain waste-waste interactions might occur must be realistic and allow discrimination between wastes; and (3) as often as possible, guidelines for applying the model must be concrete.

The three major model components are discussed below.

Quantity

Waste quantity is still the dominant consideration. A PRP's participation in a cost allocation program is obviously based on the presence of his waste at the site. The total weight or volume attributed to the waste is Factor A in Equation 1.

Biological (Toxic) Factors

The potential of a waste to do harm to human health or the environment directly impacts the effort and cost of waste site cleanup. Cleanup considerations which reflect concern for this potential include:

- Extent of cleanup effort
- Cleanup methodology
- Long-term monitoring and testing
- Public interest

The difference in cleanup effort required for a non-hazardous or low hazard project and that required for a high hazard project is substantial. The difference may range from selected (or limited) waste removal and/or site capping in the low hazard case to extensive material removal, subsequent treatment and disposal of contaminated groundwater, construction of containment facilities, etc., in the high hazard case.

The cleanup protocol necessary to safely handle wastes and accomplish assigned cleanup work will generally be much more rigorous for a high hazard site than for a non-hazardous site. The degree of worker protection and the corresponding worker efficiency can vary substantially.

The number of monitoring locations and the sophistication and expense of well installation and analytical testing will invariably reflect the potential hazard posed by the site.

Experience has shown that public sentiment and non-technical involvement can have a significant impact on the level of effort involved in remedial activities.

The above considerations led to the assignment of weighting factors of 1, 3, 5 and 7 for each of the subfactors contributing to the Biological Factor. However, if the subfactors are considered to be interactive in any way, the weight given to the Biological Factor is disproportionate. Therefore, only the subfactor with the highest score is considered and this weight is assigned as the Biological Factor (B) in Equation 1.

Physical Factors

Wastes typically have differing physical characteristics which impact cleanup costs differently. The Physical Factor C in Equation 1 is the sum of weightings given to seven individual physical components:

$$\text{Physical Factor (C)} = (CON + M + A + P + I + COR + R)\qquad(2)$$

Where:
  CON = Consistency
    M = Mobility
    A = Activity*
    P = Persistence
    I = Ignitability
  COR = Corrosivity
    R = Reactivity

$$*\text{Activity} = (Am + Ar + Ae)/6\qquad(3)$$

Where:
  $$Am = A + B + C\qquad(4)$$
  $$Ar = D + E\qquad(5)$$
  $$Ae = F + G\qquad(6)$$

  A = Response to Water
  B = Response to Chlorinated Solvents
  C = Response to Hydrocarbon Solvents
  D = Reactivity w/Organics
  E = Reactivity w/Inorganics
  F = Solvent Strength
  G = Absorptive Capacity

Consistency

Costs for solidification of wastes vary by a factor of 3 between solids and liquids. In the case where treatment and discharge of a liquid aqueous waste is selected as an alternative to solidification, the cost differential between a solid waste and a liquid is still a factor of 3. Thus, the weighting for consistency becomes 1 for solids, 2 for sludges and 3 for liquids.

Mobility

Costs associated with the mobility of wastes reflect the potential of a given waste to move (rather than actual measured movement of the wastes). It was necessary to limit the concept of mobility to a general potential to move in order to keep the model site independent. Briefly, the weighting for mobility is 1 for solids, 2 for sludges, 3 for permeants similar to water and 4 for permeants which tend to move faster than water. The mobility factor does not address the cost of cleaning up off-site contamination resulting from waste migration. Application of the model to off-site contamination cleanup requires site-specific information.

Activity

Since it probably is not fair to allocate costs based only on the possibility that a certain interaction may potentially occur if the right materials come together under the right conditions, the effects on the allocation factor must be tempered. This has been achieved in the activity term.

Within the physical factor "activity", three sets of subfactors have been identified. These subfactors (a through g) comprise a mobility term—Am; a reactivity term—Ar; and an effects term—Ae.

Weightings of 1, 2 and 3 are assigned to subfactors a through f and a weighting of −1 or 0 is assigned to subfactor g. A conservative approach dictates that terms a through f are all positive, presuming that if an interaction does occur then the results will be to enhance either the mobility or the toxicity of something at the waste site. Only term g can affect a reduction in the activity factor term.

Persistence

Persistence weightings of 1 through 4 are similar to those used by the USEPA in the "Mitre Model". The degree of persistence affects the time-dependent post-cleanup requirements for site monitoring.

Ignitability, Corrosivity and Reactivity

Weightings for ignitability (0 through 4), corrosivity (0 and 1) and reactivity (0 through 4) are similar to widely used scales in USEPA regulations. Ignitability impacts normal cleanup costs because of a greatly increased handling problem encountered when handling ignitable wastes. Scoring corrosivity and reactivity is reserved for containerized waste.

STRENGTHS OF THE CCA MODEL

The CCA model embodies several distinct features and affords negotiating parties an independent cost allocation mechanism:
- It can be applied to essentially any waste site
- It can be applied prior to site investigation for apportionment of on-site cleanup cost; application for off-site cleanup cost allocation requires site-specific information
- Input data are waste-related, not site-related
- It can be readily updated as new information becomes available
- It provides incentive for full disclosure of waste characterization data

The CCA model is a viable mechanism for apportioning cleanup costs for waste sites. At a minimum, it provides a reasonable basis for negotiations among PRPs.

USE OF THE CCA MODEL

Applying the CCA model requires information about the wastes present at a site. The information can be either general and limited or comprehensive. Obviously, the more detailed the waste data base the more accurate the model output. Specific input for the model includes the following:
- Identification of the participants in cleanup cost apportionment (potentially responsible parties, PRPs)
- Description of individual wastes sufficient for characterization and evaluation; wastes which are unknown or inadequately de-

scribed are scored conservatively (high) by the model, thus precluding under-statement or possible waste impact
- Determination of quantities of individual waste types attributable to each PRP
- Identification of consistency of each waste at the time of its deposition at the site; wastes with unknown consistencies are conservatively considered to be liquids
- Determination of locations of deposited wastes, migration plumes (surface and subsurface) and other evidence which confirms appropriateness of subdividing cleanup cost activities among fewer than all PRPs; in the absence of such information wastes are assumed to be co-mingled.

To the extent possible, the above information should be substantiated by shipping documents, purchase orders, invoices, analytical test results, knowledgeable testimony, etc.

Effective application of the CCA Model presupposes that input data (waste quantities, biological factor assignments and physical factor assignments) have been properly developed and, where appropriate, reasonable assumptions made. In particular, evaluation and scoring of waste-related biological (toxic) factors and physical factors must be accomplished by persons with the technical background to make realistic, defendable judgments.

MODEL APPLICATION

Generally, there will be both a static and a dynamic phase to the cleanup of a waste site. The static phase is concerned with the site proper (as defined previously). The dynamic phase is concerned with efforts to mitigate contamination which has migrated (surface or subsurface) away from the site. The CCA model effectively addresses the static phase, cost apportionment given only knowledge of the wastes. Application of the model to the dynamic phase requires, in addition to input waste information, sufficient site-specific information to establish what wastes (or waste constituents) have moved off-site, the extent of their movement and their impact on cleanup cost for areas beyond "site" limits.

EXAMPLES OF THE MODEL'S APPLICATION

Use of the model for apportionment of static phase cleanup cost is illustrated by the three cases below, which reflect increasingly more complex (and realistic) waste-related conditions. It should be assumed that in each case the three PRPs have numerous types of wastes comprising the quantities noted below.

Company I	— 1000 tons
Company II	— 2000 tons
Company III	— 3000 tons

Case 1:
All wastes have proportionately the same biological and physical effects for each PRP.
Case 2:
Waste quantities and physical characteristics are the same as for Case 1, but waste biological (toxic) effects differ for each PRP.
Case 3:
Waste quantities are the same as for Case 1, but waste biological (toxic) effects and physical characteristics differ for each PRP.

The over-simplified model application for these three cases is shown in Table 1; a summary of the allocation percentages for each case is presented below.

COST ALLOCATION (%)

Case	Co. I	Co. II	Co. III
1	17	33	50
2	35	50	15
3	50	44	6

These simplified cases illustrate the significant impact on cleanup cost apportionment recognized by the CCA model as pertinent

Table 1
Example Cases

CASE 1

COMPANY	(A) WASTE QUANTITY	(B) BIOLOGICAL FACTOR	(C) PHYSICAL FACTOR	(D) AxBxC	(D)/(E) COST ALLOC. FACTOR
I	1000	5	8	40,000	0.17
II	2000	5	8	80,000	0.33
III	3000	5	8	120,000	0.50
			(E)	240,000	1.00

Cleanup Cost Apportionment: Company I - 17%
Company II - 33%
Company III - 50%

CASE 2

COMPANY	(A) WASTE QUANTITY	(B) BIOLOGICAL FACTOR	(C) PHYSICAL FACTOR	(D) AxBxC	(D)/(E) COST ALLOC. FACTOR
I	1000	7	8	56,000	0.35
II	2000	5	8	80,000	0.50
III	3000	1	8	24,000	0.15
			(E)	160,000	1.00

Cleanup Cost Apportionment: Company I - 35%
Company II - 50%
Company III - 15%

CASE 3

COMPANY	(A) WASTE QUANTITY	(B) BIOLOGICAL FACTOR	(C) PHYSICAL FACTOR	(D) AxBxC	(D)/(E) COST ALLOC. FACTOR
I	1000	7	13	91,000	0.50
II	2000	5	8	80,000	0.44
III	3000	1	4	12,000	0.06
			(E)	183,000	1.00

Cleanup Cost Apportionment: Company I - 50%
Company II - 44%
Company III - 06%

waste-related factors are varied. A more comprehensive example of how to use the CCA model is presented in Reference 1.

Discussions of the general model application to the PPI site have been presented in previous papers.[3,4] The PPI Superfund site (actually two sites) encompassed what would be considered a wide range of waste materials and site conditions.

SPECIAL CONSIDERATIONS

The weighting of the CCA model factors reflects typical wastes which may be found at abandoned wastes sites. There will be special cases in which the wastes are inadequately handled by the model. Such cases will involve wastes which have extreme toxicity and high persistence, including dioxin (2, 3, 7, 8 tetrachlorodibenzo-p-dioxin) and radioactive isotopes.

The problems presented by these types of wastes are two-fold:
- The waste must be removed to very low levels of background contamination; cleaning a site to very low background levels usually means that inordinately large amounts of background soil and groundwater must be removed and/or treated
- High levels of personnel health and safety protection must be maintained at all times in all areas

These problems can add to the cost in a very dramatic way.

Since the weighting factor for toxicity reflects the cost of the extent of cleanup effort, special cleanup methodology, long-term monitoring and testing and public interest considerations, this factor must be modified or overriden for special considerations.

There may be several ways to approach this problem. However, the most practical would appear to be to apply the model as if the problem waste were not present. The absolute cost of cleanup would be calculated as if the problem waste were not present and again for the total situation as it really exists. The costs for the hypothetical closure would be allocated according to the model and the excess costs would be allocated to the generator who disposed of the problem waste.

CONCLUSIONS

Historically, allocation of cleanup costs for waste sites has been a source of confusion and frustration. The CCA model is a viable mechanism for apportioning cleanup costs for waste sites. The model considers not only volume but also the risks posed by and the physical characteristics of individual wastes as they impact cleanup costs.

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REMEDIAL COST ESTIMATION SYSTEM FOR SUPERFUND SITES

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INTRODUCTION

The work described in this paper is part of an ongoing project sponsored by the Office of the Comptroller and the Office of Emergency and Remedial Response of the USEPA. The primary purpose of this project is to develop an estimate of the total costs of remedial actions at sites that are currently on or might be added to the National Priorities List (Superfund sites) as an aid to budgeting, planning and policy development. The first phase of the project took place from September to December 1983 and is described in this paper.

When this project started, remedial activity had only been completed at a small number of the over 500 Superfund sites. Furthermore, only a small number of feasibility studies that prescribed alternatives and estimated potential remedial costs had been completed. Thus the available database on actual and estimated remedial costs represented a small percentage of the Superfund sites and did not by itself allow one to draw strong conclusions concerning the average cost per site across the entire National Priorities List (NPL).

Consequently, it was necessary to develop additional information that could be used to estimate the costs at the majority of NPL sites for which credible and consistent estimates did not currently exist. However, it was also clear that some simplification of the problem was necessary since detailed cost estimates could not be developed for all sites, or even for one site, within the scope of this effort.

In many such cases, the simplification takes the form of a model plant or model site that can be used to represent a large number of similar situations and thus facilitate extrapolation. The authors' judgment was that in the case of NPL sites the variability of the type and scope of problems among sites would make it difficult to identify or create one or more model sites that would be representative of a large number of similar sites.

For example, a large number of sites are landfills. Relative to other categories such as chemical plants or manufacturing plants, landfills probably have a low degree of variation in cost. However, there are substantial differences among landfills: size, topography, extent of subsurface contamination, leachate formation, proximity to houses and wells and degree of groundwater contamination. This variability makes it very difficult to identify a particular landfill that would on average be representative. Furthermore, even if enough information about other landfills on the NPL were available so that a representative landfill could be designed, there would be no assurance that it would be representative of landfills that might be added to the NPL in the future.

Rather than try to design representative sites, the authors attempted to deal directly with the diversity in problems among Superfund sites. Each site was viewed as being composed of one or more attributes (e.g., drums, contaminated soil, groundwater contamination) that in most cases would require specific remedial actions (e.g., drum removal, soil removal and capping, groundwater treatment). The costs at a specific site could then be estimated by a three-step process in which (1) data concerning the problems at the site were collected, (2) the remedial actions likely to be taken in response to these problems were determined and (3) cost estimates were developed for each remedial action using functions that incorporated the major cost-creating factors (e.g., the number of drums and the distance to a secure landfill).

By focusing on a relatively small number of attributes that give rise to the major remedial costs and by developing cost functions that could be used repetitively, a large number of reasonably accurate and unbiased site-specific cost estimates could be developed at relatively low cost. This would enable the wide diversity in site characteristics to be considered directly and avoid the need to extrapolate to the entire NPL from a small sample. This approach would also establish a framework for considering additional sites that could be added to the NPL, for evaluating expeditiously the cost implications of the additional site information developed as site studies progressed and for considering the cost impacts of changes in USEPA policies regarding acceptable remedial actions.

MAKING THE APPROACH OPERATIONAL

To make this approach work, a set of decision criteria was developed to apply to aspects of the problem at each site to determine the types of remedial actions that would generally be applied. Functions were also developed that would use site data to estimate the costs of applying a particular type of remedial action. Finally, the data required by the methodology were collected through direct contact with the USEPA regional personnel most familiar with each site.

Once data had been collected at each site, the costing procedure involved the following actions:

- Project members reviewed the data and determined what remedial actions would be likely at each site. The selection was usually based on the decision criteria but was often influenced by the judgment of the USEPA site manager or the judgment of project personnel based on discussions with the site manager.
- Cost estimates were generated for each remedial action to be taken at a site using the cost functions. For sites where engineering studies or actual costs for remedial actions were available, these were used instead of the estimates.

•Cost estimates were reviewed to ensure reasonableness. In many cases, USEPA site managers had good estimates of what costs would be, and our estimated costs were compared to these to ensure that our approach was reasonable. When this occurred, the review process identified costs for particular remedial actions that seemed extremely high. In such cases, these costs were reviewed to see if similarly effective but lower cost alternatives (e.g., containment and capping instead of massive soil removal) were available. If so, costs were recalculated.

DECISION CRITERIA

To implement the costing system, it was necessary to have criteria or rules that could be used to decide what remedial actions would be likely to occur given the nature of the problems at a site. To develop these rules, the authors first discussed the situations at a number of Superfund sites with regional USEPA site managers. For many of these sites, specific remedial actions had been taken or could be anticipated with some confidence. The problems and expected remedial actions at these sites generally followed patterns that were consistent with a preliminary set of decision criteria that were developed.

The criteria have undergone some revision as a result of cleanup experience gained in several USEPA regions and will be further refined both as additional site information is collected and as USEPA policy with regard to problems such as groundwater treatment or handling of contaminated soil evolves. The criteria in each problem area that were found to be the most generally applicable in late 1983 are discussed in the following sections.

Drums

•If above ground drums or barrels exist, then remove them to an off-site hazardous waste disposal site (HWDS)
•If buried drums exist near the surface, then excavate and remove them to an off-site HWDS unless they are in a landfill that will be capped.
•If buried drums exist well below surface, then cap the site.

Tanks

•If tanks containing liquids or sludges exist above ground, then drain contents and remove to HWDS; then decontaminate and dismantle tanks for salvage or disposal.
•If tanks containing liquids or sludges exist below ground, then drain contents and cap area.

Lagoons

•If lagoons contain organics in liquid phase, then drain liquids and transport to HWDS.
•If lagoons contain aqueous solution, then either drain and transport to treatment or disposal site, or drain, treat on-site and discharge to municipal sewage treatment, depending upon which is less expensive.
•If lagoons contain sludges with volatile or highly soluble chemicals, then excavate the sludge and transport to HWDS.
•If lagoons contain other sludges, then cover and cap.
•All lagoons are backfilled and covered with an impermeable barrier or cap.

Contaminated Soil

•If surface soil is highly contaminated with PCBs, dioxin, pesticides or other highly toxic or carcinogenic substances, then excavate soil, transport to HWDS and cap area.
•If highly contaminated hot spots exist, then excavate soil, transport to HWDS and cap area.
•If other types of contaminated surface soil exist, then cap area.

Buildings and Equipment

•If contaminated buildings or equipment exist, then decontaminate and dismantle for scrap or salvage.

Leachate

•If leachate is being produced from a landfill, dump or other site, then implement a collection and contamination removal system.

Surface Water Diversion

•If the topography of a site is such that off-site water would run through a contaminated area, then implement upgradient surface water diversion.

Capping

•If contaminated soil exists with which people or animals could come in contact, then cap with clay.
•If contamination exists on or below the surface and threatens groundwater and if the contaminant is a volatile organic or highly soluble chemical, then cap with clay and plastic liner; otherwise cap with clay.
•If contamination exists in dirt roadways or parking lots, cap with clay and asphalt.
•If contaminated surface runoff to off-site areas or surface waters exists, then cap site with clay.

Fencing

•If public access to a site exists, then fence entire site.

On-Site Groundwater Treatment

•If groundwater under a site is contaminated and the natural groundwater flow creates a potential or immediate threat to drinking water for which there are no economic alternatives or to other surface waters used for drinking, recreation or commercial purposes, then treat groundwater on site at the rate of 5,000 gal/day/acre of contaminated area. Various probabilities are assigned to such treatment depending upon whether groundwater contamination is confirmed, likely, possible or unlikely.

Off-Site Groundwater Treatment

•If contaminated groundwater has migrated off-site and the natural groundwater flow creates a potential or immediate threat to drinking water for which there are no economic alternatives or to other surface waters used for drinking, recreation or commercial purposes, then treat groundwater on-site at the rate of 5,000 gal/day/acre of contaminated area.

Well Problems

•If public wells are contaminated or imminently threatened by contaminated groundwater, then either relocate the well field if an alternative well field site is close enough to be economic or install a water treatment plant.
•If private wells are contaminated or imminently threatened by contaminated groundwater, then either relocate wells if cost effective, hook up homes or industries to municipal supplies if cost effective or treat private wells.

Slurry Walls

•If groundwater would run through contaminated subsurface areas of a site, then build a slurry wall to divert groundwater or contain contamination if such construction is possible.
•If on-site groundwater treatment is chosen as a remedial action, then build a slurry wall if such construction is possible unless the threat of groundwater contamination is sufficiently distant in time that treatment without a slurry wall is adequate.

COST EQUATIONS

Once the decisions have been made on likely remedies, the cost functions are applied to generate estimates for the capital, operating and maintenance costs associated with each remedial action. For this paper, costs were developed for the most common remedial activities based on information available from the following sources:

•Site feasibility studies
•Vendor quotations
•Contractor bids
•Actual remedial construction costs
•Publications on hazardous waste treatment projects
•In-house engineering and cost data

For some remedial actions, costs are reasonably well known while for others the lack of data and actual site experience makes the development of precise functions more difficult. The development of the cost functions is continuing as part of an ongoing effort. Without going into great detail concerning the specific numbers used, the following sections describe the nature of the functions used in this system.

Drums

Drums containing hazardous chemicals or materials are sampled, staged, overpacked when necessary and transported to an appropriate site for disposal. The cost elements included in the cost function are the number of drums, the percentage requiring overpacking, the contents of the drums and the transport distance.

Tanks

At some sites, hazardous chemicals and materials have been stored in tanks usually located above ground. For all sites it is assumed that the hazardous contents are removed from the tanks and transported to a hazardous disposal or treatment site. The cost include: (1) removal from tanks to tank trucks, (2) haulage to disposal site and (3) disposal. The costs depend on the quantities and composition of the tank contents, the distance to a disposal site and the costs for disposal (including incineration). It is assumed that the tanks are decontaminated, dismantled and removed from the site if they are on the surface. Only in certain instances are underground tanks excavated and removed from the site.

Lagoons, Ponds and Pits

At many sites, aqueous solutions, solvents, oils, acids and other chemicals that were contaminated with hazardous materials were collected and stored in lagoons, ponds or pits. For this study, it is assumed that the organics are removed to hazardous waste disposal sites.

The quantity of the aqueous phase is important; small volumes are assumed to be removed to approved disposal sites, but very large volumes could be treated on-site. Sludge at the bottom of lagoons, ponds and pits is excavated and removed from the site. All areas are assumed to be backfilled and capped to prevent infiltration of precipitation.

The removal of solutions and sludges is expensive; in some remedial actions, the contamination may be fixed in place and capped, if the hazardous material can be rendered stable and innocuous.

Contaminated Soil

It is assumed that highly contaminated soil is excavated and removed to a disposal site. Highly contaminated soils are those that include highly toxic or carcinogenic substances such as PCBs, volatile organics or pesticides. If the costs for excavation, transport and disposal are greater than on-site burial in an approved disposal area, then on-site burial costs are used.

Buildings

Some sites have buildings that must be decontaminated and removed. Disposal would either be by on-site burial, removal to an acceptable waste dump or, if sufficient steel were involved, sale for scrap. Cost is a function of building floor space and composition (i.e., brick, concrete, steel).

Leachate Collection Systems

At some landfills and waste dumps, surface and underground waters flow through contaminated soils and materials and carry dissolved hazardous materials away from the contaminated area.

Drainage systems can be constructed around the contaminated area to collect the solutions, and a small treatment plant can be installed to collect the contaminated liquids for removal from the site or for treatment prior to discharge. There are many types of drainage systems and costs will vary from depth below the surface and length. By correlating cost data from several installed leachate collections systems, the authors have developed a cost function that varies according to the length of the collection system and the volume of leachate treated.

Diversion Trenches

At some sites, surface water that tends to flow into contaminated areas (such as landfills or dump areas) can be diverted around the area by trenches. The design and length of trenches, dikes or berms is site-dependent. The authors have used some general correlations of costs to develop a function that varies by length of the trench.

Capping

Impermeable barriers are installed above many contaminated areas to preclude the flow of precipitation through the contaminated area. The authors have considered three general types of caps:
•Clay covered with topsoil and vegetation—general application
•Clay plus synthetic liner covered with topsoil and vegetation— volatile organics and highly soluble chemicals as contaminants
•Asphalt—roads and parking areas

Operating and maintenance costs are assumed at 5% of the initial capital costs. The costs vary according to the surface area of the cap required and were derived from feasibility studies, engineering handbooks and vendor quotation data.

Slurry Walls

Underground water contamination may be contained in-place by installation of a low permeability wall around the perimeter of the contaminated area. Usually the wall will extend from the surface down to the bedrock. The principal cost parameters are the length and depth of the wall. Unit costs appear to increase as depth increases beyond 30 ft.

Fencing

All hazardous waste sites, except those that would normally be fenced, are assumed to be enclosed by a cyclone fence. Appropriate gates and signs are included in the costs.

Groundwater Treatment

At some sites, a system of wells will be installed. Contaminated water will be pumped to the surface where the hazardous materials will be removed and collected and clean water reinjected into the ground. The number of wells and the amount of water that can be pumped and processed depend on the geology of the site and the geochemistry, permeability and porosity of the soil. Further, it is possible to vary the total rate of pumping and the number of years of operation.

Information on pumping of groundwater is available for only a few sites, but a range of 1,000 to 18,000 gal/day/acre at contaminated areas has been seen in site design studies. The capital and annual operating costs are calculated based on perceptions of the site hydrology (and hence an estimate of solution flow) and the types of contamination in the groundwater which determine the treatment process.

Wells

Many of the Superfund sites include municipal wells that have contaminated water. At numerous other hazardous waste sites, public or private drinking water sources are threatened by migration of contaminants in groundwater. Remedial action in many instances requires either: (1) development of alternative water supplies or (2) treatment of water sources. The cost elements associated with these activities may include:

NUMBER OF SITES
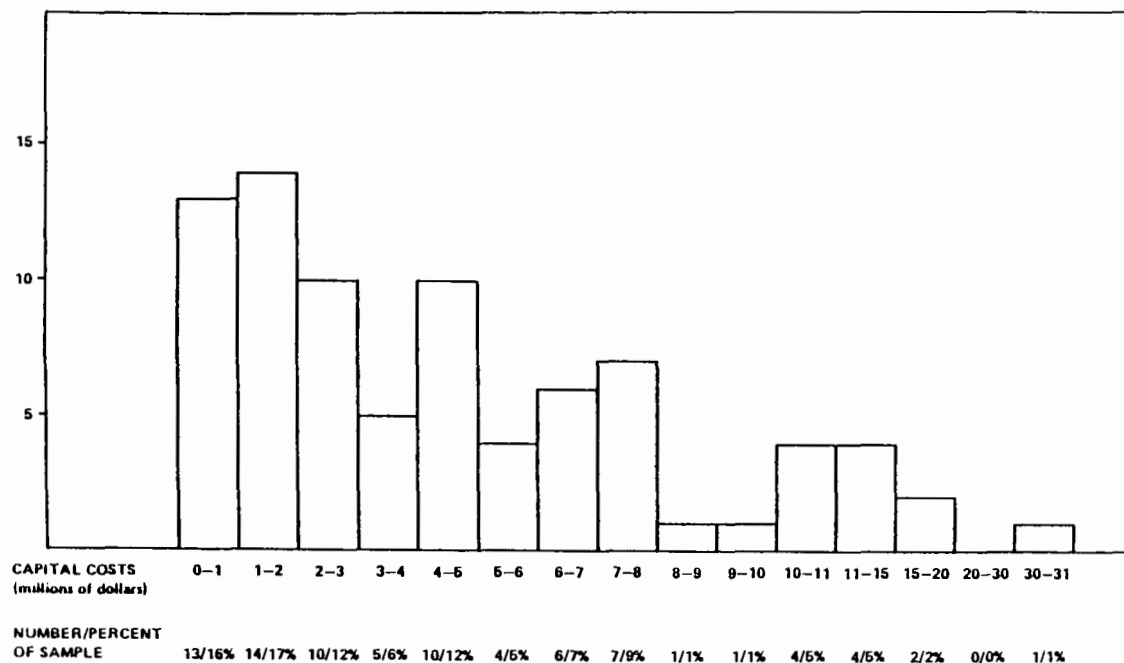
Figure 1
Frequency Distribution of Capital Costs of Remedial Actions
for Estimated Sites

•A new house well
•The relocation of municipal wells to an uncontaminated area
•The connection of houses to existing municipal water supplies
•The treatment of municipal water

RESULTS

During visits to USEPA regional offices in Regions 1, 2 and 3 in late 1983, the authors collected information concerning 88 hazardous waste sites. Of these 88 sites, 82 were amenable to costing by the system; the other six were extraordinary sites such as Love Canal that had problems that could not be handled accurately by the system. Of sites amenable to costing, seven were in Region 1, 38 in Region 2 and 37 in Region 3.

Regional and state costs of remedial actions at the sites estimated by the system are given in Table 1. The average capital cost per site figures exhibit a significant variation between states and regions. This analysis supports the assumption that it would be difficult to find a small sample of sites that would be representative of the universe. It also indicates, not surprisingly, that there may be systematic differences in the types of problems experienced at sites in different regions of the country. For example, for the three states with the greatest representation in our sample, average capital costs per site vary from $8.1 million in New Jersey to $4.9 million in New York and $3.0 million in Pennsylvania.

Another aspect of the variability among costs at NPL sites is shown in the histogram in Figure 1 which groups sites according to remedial capital costs. The histogram demonstrates the large range of remedial costs and suggests that the distribution of costs has its greatest concentration at low levels and declines steadily, as opposed to exhibiting the more typical bell shaped curve of the normal distribution. Thus the average cost of $5.0 million for the sites in this sample is the result of averaging a few sites with relatively high costs with a larger number of sites with relatively low costs.

TOTAL COSTS OF REMEDIAL ACTIONS AT ALL NPL SITES

One of the major objectives of this work was to develop a methodology that could be used expeditiously and inexpensively to derive estimates for remedial costs at nearly all sites on the NPL. By

so doing, the need to develop total cost estimates on the basis of extrapolation from relatively few sites could be avoided. In the continuing effort, a significant number of additional sites will be added to the database. However, some form of extrapolation was required to derive a total cost estimated based on the initial sample of 82 sites.

The extrapolation procedure that was used addressed the two potential sources of bias in the sample. One potential problem was that the sample only includes sites that are in some sense "typical" hazardous waste sites and excludes "extraordinary" sites such as Love Canal that are not amendable to costing by the system and where remedial costs are generally much higher. The other problem

Table 1
Cost Results by Region and by State

Region/State	Number of Sites	Capital Costs per Site ($ Million)	Annual O&M Costs per Site ($ Million)
REGION 1			
Massachusetts New Hampshire	4	8.4	0.2
Rhode Island Vermont	3	4.8	0.4
Region 1 Average	7	6.9	0.3
REGION 2			
New Jersey	18	8.1	0.4
New York	19	4.9	0.4
Region 2 Average	37	6.5	0.4
REGION 3			
Delaware	9	5.6	0.3
Maryland	3	2.3	0.2
Pennsylvania	19	3.0	0.2
Virginia	4	2.9	0.1
West Virginia	3	1.8	0.1
Region 3 Average	38	3.1	7.0/0.2
Sample Average	82	5.0	22.9/0.3

Table 2
Calculation of Total Cost

Type of Site	Number in Sample	Number on NPL	Capital Cost ($ Millions)	O&M Cost ($ Millions)
1. Landfill	30	118	891	66
2. Wells	7	49	233	24
3. Industrial Dumps and Treatment	25	136	579	18
4. Chemical Plants/ Refineries	10	91	599	24
5. Manufacturing Plants	4	95	333	19
6. Water Bodies	--	11	98	4
7. Pure Lagoons	4	22	56	2
8. Military Sites	1	3	4	0
9. City Contamination	--	6	46	1
10. Radioactive Sites	--	5	60	1
11. Mines and Tailings	1	8	71	3
12. Housing Areas/ Farms	--	1	3	0
13. Presque Isle	--	1	0	0
14. Extraordinary Sites	--	(19)	950	29
TOTAL COSTS			**3,923**	**193**

was that the mixture of sites in the sample may not have been representative of the total mix of sites in the NPL (e.g., too many landfills, too few manufacturing plants).

To address the first problem, the authors made additional provision in the total cost estimates to account for the number of "extraordinary" sites that were anticipated to be on the NPL.

To address the second problem, each site on the NPL was assigned to one of 13 categories intended to include a number of sites that would be characterized by problems of similar origin and nature. The majority of sites fell into one of the following classifications: landfills, wells, industrial dumps and treatment facilities, chemical plants/refineries, manufacturing plants, lagoons and water bodies.* Results from the 82 sites were used to develop estimates of average costs for "typical" sites in each category. These figures were then used to develop estimates of total remedial costs for each category and ultimately for the entire NPL.

The resulting cost estimates are found in Table 2. The preliminary estimates of capital and first-year operating and maintenance costs associated with remedial actions at all NPL sites are $3.9 billion and $193 million respectively, or $7.2 million and $0.4 million per site. However, these results are preliminary and are, in fact, likely to change as the research progresses. Since the authors' initial work, the USEPA policy with regard to acceptable remedial action at sites has moved in a direction that requires more groundwater treatment and more removal or containment of contaminated soil. This emphasis will necessitate revisions in the deci-

*There are many possible groupings for hazardous waste sites and judgment was used in developing groupings that were believed to be adequate for the purposes of this preliminary extrapolation. Judgment was also used in assigning sites to categories in cases where distinctions were not obvious.

sion rules used in this sytem that will probably cause an increase in these estimates of remedial costs per site.

APPLICATIONS OF THE METHODOLOGY

Prior to the commencement of corrective action at any hazardous waste site, it is necessary to conduct a detailed analysis of the site problems and to evaluate alternative approaches to cleanup. It is mandatory to conduct remedial investigations and feasibility studies prior to conducting a detailed design of a selected plan to correct site problems. The sequence of studies requires a long period of time (i.e., from several months to more than a year) and is very expensive (hundreds of thousands of dollars) for each site. While it is necessary to follow this approach prior to commitment of millions of dollars of construction funds for cleanup at each site, there are situations that warrant a more rapid and less costly process to project the cost of cleanup and assess the alternatives.

This project was initiated to help management and planning personnel at the USEPA cope with the total cost of the Superfund Program when a very small fraction of the sites had been completely analyzed. This system, with appropriate update, will continue to be used as a tool to assess the cost of the Superfund program. Furthermore, as government policy changes, this methodology provides a rapid and relatively low cost means to assess the cost impact of new policies on Superfund.

Apart from use by the USEPA for its management and budget analysis, the authors believe that this program has value in several other areas. One application is in a preliminary assessment of newly discovered or newly listed hazardous waste sites.

Using very preliminary data about the nature of the contamination at a site, it is possible to estimate quickly the cost of cleanup using data presented here. While this methodology is not a substitute for detailed engineering feasibility studies and designs, it can be used by industrial firms and responsible parties to assess the likely ranges of the costs of a site cleanup. In addition, this system can be used to rank order the problem areas at each site in terms of the approximate cost of the solution. This ranking would enable subsequent studies to focus on the problems that have the greatest impact on and contribute the greatest uncertainty to total remedial costs at a site.

Another application of this methodology would be to assess the needs for further research that could significantly reduce the future costs of Superfund and for parties responsible for contaminated property. The preliminary results of this study indicate that the most expensive corrective actions that involve the greatest costs across all NPL sites are: (1) capping, (2) leachate collection and treatment systems, (3) treatment of underground and surface water and (4) slurry walls. Some corrective actions, however, do not have established, engineered solutions and fundamental engineering design data are not available. Identifying the remedial activities that involve the greatest cost expenditures may help target research to the areas that will have the greatest beneficial impact on the total cost and effectiveness of Superfund actions.

COST ANALYSIS FOR REMEDIAL ACTIONS UNDER SUPERFUND

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INTRODUCTION

In response to risks posed by uncontrolled hazardous waste sites to public health and environment, Congress enacted the CERCLA in December, 1980. The Act authorized the government to establish the Hazardous Substance Response Trust Fund (the Fund) to finance the necessary responses to any release or threats of release from hazardous waste sites. While the primary goal of the Act is clearly to protect public health and environment from release of hazardous substances, it also requires remedial responses to be "cost-effective" and within the financial limits of the Fund. Cost-effectiveness considerations must be incorporated into the selection of appropriate remedial actions with the goal of ensuring the greatest improvement in protection of public health and the environment for the least cost.

Cost considerations are a key component in various steps of the remedial action alternative selection process:
- Screening of alternative remedial measures
- Detailed analysis of the alternatives
- Selection of the alternatives
- Balancing the cost of the selected measures against the availability of money in the Fund

In addition, the potential for cost recovery from potentially responsible parties requires a thorough cost documentation.

In this paper, the authors summarize the results of an effort undertaken by the USEPA to develop costing information from which a consistent cost-effectiveness program could be developed.

NEED FOR COST INFORMATION

The USEPA, responding to the requirements of the CERCLA, reviewed existing information regarding available cost data which could provide: (1) a basis for future costing and (2) a consistent approach such that remedial actions could be compared during a cost-effectiveness analysis. Cost information was available from case studies of remedial actions, direct field construction activities and standard references. Similarly, cost analysis procedures were available from other engineering programs. Unfortunately, the available information which could be applied directly to uncontrolled hazardous waste sites was not adequate for consistent cost estimations.

To supplement available information, the USEPA undertook an effort to:
- Collect relevant, consistent and reliable cost data that could be used for cost estimates for remedial action at different levels of the selection process
- Develop specific procedures for cost estimating and economic analysis required for remedial action planning

Through these two activities, the USEPA can provide necessary guidance and baseline cost information for USEPA Regional Project Managers, contractors performing remedial investigation/feasibility studies, private parties undertaking hazardous waste cleanup activities and State and local remedial action personnel. Further, concise economic analysis will demonstrate to the public, Congress and other interested parties that the USEPA and CERCLA are adequately addressing the problems of uncontrolled hazardous waste cleanup.

COST ANALYSIS TOOLS

The USEPA's Municipal Environmental Research Laboratory and Office of Emergency and Remedial Response, with input from other USEPA offices, regional offices, environmental organizations, State and local institutions and private parties, have developed resource documents to fill the gaps in guidance for costing analysis for uncontrolled hazardous waste-site responses. Specifically, the USEPA cost guidance information is provided in the following draft documents:
- Guidance for Feasibility Studies Under CERCLA
- Procedures for Cost Analysis for Remedial Action Under Superfund
- Compendium of Cost of Remedial Technology at Hazardous Waste Sites

These documents are undergoing final review and will be issued shortly for use by the remedial response community in the development of costs for remedial action planning. The three documents are examples of three levels of USEPA guidance on CERCLA actions. The Guidance for Feasibility Studies Under CERCLA is an example of a "what to" manual.

Procedures for Cost Analysis for Remedial Action Under Superfund is a "how to" manual designed to define the process set forth in the "what do" manual (Guidance for Feasibility Studies).

Lastly, the Compendium of Cost of Remedial Technology is an example of sour information required to follow the process set forth in the "how to" manual (Procedures for Cost Analysis for Remedial Action Under CERCLA). The Office of Emergency and Remedial Response is preparing a comprehensive annotated list of all such guidance documents. A discussion of the three costing documents follows.

Guidance for Feasibility Studies Under CERCLA

A standard process has been established by the USEPA for evaluating remedial action alternatives in terms of cost and effectiveness. This process is set forth in the Guidance for Feasibility Studies Under CERCLA. The Guidance provides a structure for

Regional Project Managers, potentially responsible parties and others who have responsibility to prepare documentation supporting remedial actions performed under CERCLA and the National Contingency Plan. As part of the process, a recommended approach to development and analysis of costs of remedial action alternatives is given.

The Guidance presents steps which should be followed to develop costs as input to the cost-effectiveness analysis. That is, the Guidance presents "what to do" rather than "how to" procedures. Specific procedures are presented in the Remedial Action Costing Procedures Manual.

Costing Procedures Manual

The Procedures for Cost Analysis for Remedial Action Under CERCLA presents specific procedures for various phases of the remedial action planning process. Procedures are provided to assist in:

• Preparation of an initial assessment of remedial action alternatives to establish a general cost for the remedial investigation/feasibility study process and initial remedial measures

• Screening of remedial action alternatives during the feasibility study to eliminate those alternatives for which the costs are substantially greater than other alternatives and yet do not provide a commensurate public health or environmental benefit

• Preparation of detailed cost estimates for feasibility studies to aid in selecting a remedial action alternative

The Costing Procedures Manual presents procedures and provides worksheets to accomplish the cost analysis objectives of the above phases. The guidance presented has been developed for generalized conditions at uncontrolled hazardous waste disposal sites.

The Manual defines procedures for estimating costs for sites on the NPL prior to initiation of the remedial investigation. At this stage, an assessment formerly known as the Remedial Action Master Plan (RAMP), is completed. It summarizes existing site information, addresses the types of remedial activities required at the site, addresses community relations concerns at the site and estimates budget and schedule requirements for subsequent remedial response activities. The USEPA uses this report to plan future site response actions and to provide general direction to the future activities associated with the remedial investigation and feasibility study (RI/FS) process.

The Manual defines the steps of the site response assessment process and offers guidelines for costing during each of the steps. With this data, the reader can:

• Construct a site outline and identify areas which require estimating

• Assign order-of-magnitude costs to the applicable sections of the site response assessment report format

• Determine total order-of-magnitude costs for site RI/FS activities and remedial alternatives available at this stage prior to the RI/FS

The Manual concentrates on costing procedures as part of the Feasibility Study effort.

Two sets of cost estimates are generated within the overall Feasibility Study process. Initially, order-of-magnitude costs are generated to screen out disproportionately expensive alternatives. Subsequently, feasibility costs are developed and used to determine the most cost-effective alternative. While the basic procedures for generating these cost estimates are essentially identical, guidance is provided to achieve a greater level of accuracy for the feasibility costs through the use of more extensive data sources and a more detailed preliminary design based on information available from the remedial investigation.

Briefly, screening cost estimates are generated during the alternative development and screening process. These estimates are used to eliminate those alternatives whose costs are significantly greater than competing alternatives yet do not provide commensurate environmental and public health benefits. Users of the Manual are directed to the Remedial Action Cost Compendium to estimate screening costs along with other sources referenced in that docu-

ment. The accuracy of the costs should be in the + 100% tol − 50% range.

Following initial screening, a manageable number of remedial action alternatives should remain for the feasibility cost analysis. Cost estimates for feasibility cost analysis are intended to provide a measure of the total resource costs over time associated with any given remedial alternative.

Cost Compendium

The Compendium of Cost of Remedial Technology at Hazardous Waste Sites summarizes existing cost information on typical components of remedial actions. Actual expenditures and estimated costs taken from a number of sources have been assembled into this one data base. The immediate use of this centralized source of cost information is to provide consistency in various site-specific costing tasks such as remedial alternative costing called for in the Guidance for Feasibility Studies Under CERCLA and budgeting for immediate and planned removals.

The Compendium should be viewed as the first installment of an ongoing data base. It will be updated periodically as more cost information becomes available from completed Superfund responses. Cost data in the Compendium are organized according to related technologies such as "Groundwater controls." The costs given are for technologies most commonly used at uncontrolled hazardous waste sites, although some rarely used technologies are given based on engineering estimates. Typically, the number of estimates and the depth of background information provided are proportional to the frequency of use of the technology. The Compendium is a key support to the Costing Procedures Manual. The two are constructed to allow detailed interface on every stage of the cost estimating.

The Cost Compendium contains two notable features that should be mentioned. First, the Compendium stresses the comparison between estimated cost and actual expenditure from past actions. The primary reason for this is that most of the engineering estimates are not "field tested" and are based on normal construction activities, unrelated to hazardous waste cleanups. Unfortunately, there are very few documented actual expenditures for hazardous waste cleanups. As more remedial actions are completed, the data base will become more extensive. Also, although actual expenditures are in general more reliable than estimates, there is a great deal of variability in the existing data.

Second, the Cost Compendium documents the critical factors that often affect cost estimates for each technology. A typical table of actual cost expenditures from the Cost Compendium is shown in Table 1. Material in this table describes the major factors that affected the cost of each of the slurry walls (including depth, length, thickness, type of material, etc.) listed in the table. The USEPA is in the process of computerizing certain data in the Cost Compendium. When a richer data base is available, the USEPA will develop regression equations to streamline cost estimating.

PROCEDURES FOR COST ESTIMATING

The development of cost estimates for remedial action alternatives involves the following steps:

• *Estimation of Costs*—estimate capital and annual operating costs

• *Present Worth Analysis*—using estimated costs, calculate annual costs and present worth for each remedial action alternative

• *Sensitivity Analysis*—the sensitivity of cost estimates to changes in various parameters

Feasibility analysis costs are typically derived from a number of sources, including vendor estimates, and should be accurate within a range of + 50 to − 30%.

Estimation of Costs

In this section, procedures for estimating capital and annual operating costs for remedial action alternatives are given. Sunk costs are not to be included in this evaluation. Sunk costs include investments or commitments made prior to or concurrent with re-

Table 1
Slurry Wall Expenditures
(1982 Dollars)

DATA SOURCE	LENGTH & DEPTH	THICKNESS	MATERIAL	UNIT COST
US EPA ELI/JRB 1981 Pennsylvania	648 feet x 17 feet	1 foot	cement-bentonite	$31.96/sq.ft.
US EPA JRB/ELI 1979 Colorado	1,500 feet x 20 feet	30 inches	85% soil-bentonite; 15% cement	$8.33/sq.ft.
US EPA JRB Florida A (Date unknown)	2,290 feet x 30 feet	30 inches	soil-bentonite	$5.88/sq.ft.
US EPA CH2 M Hill 1982 New Hampshire	3,500 feet x 60 feet	3 feet	soil-bentonite	$5.64/sq.ft.

medial action planning. The various cost components that should be considered and sources for cost data are identified, and worksheets are provided to assist the user in organizing and presenting the cost data for each alternative.

Federal construction programs have traditionally distinguished between capital costs and operation and maintenance (O&M) costs. Federal participation in public works projects such as highways and wastewater treatment plants has been limited to construction involving the funding of a major share of projet capital costs. Following construction, costs for operation and maintenance are the responsibility of the State or local government. However, the distinction between the construction and operation phases of a Superfund cleanup response is not as easily made. The completion of construction will not achieve public health or environmental protection in many instances. Such protection may be afforded only after operation of the remedial technology for a period of time.

While the distinction between the remedial action and O&M phases of a cleanup is important for determining fund eligibility, it should not be a factor in feasibility cost analysis. The Manual provides guidance in development of comparative life-cycle cost information for the remedial action alternatives under consideration for use in the alternative selection process. These alternatives include both the remedial action and O&M phases. Thus, for the purposes of feasibility costing, the user is directed to observe the conventional distinctions between capital and O&M costs, where capital and initial construction costs are analogous.

Capital costs are those expenditures required to initiate and install a remedial action. They are exclusive of costs required to maintain or operate the action throughout its lifetime and include only those expenditures that are initially incurred to develop and incorporate a remedial action (e.g., installation of a cap or slurry trench) and major capital expenditures anticipated in future years (e.g., replacement of a cap or slurry trench). This differentiation between capital costs and operation and maintenance costs does not necessarily reflect a determination as to the "Fund" eligibility of the costs.

Direct capital costs include equipment, labor and materials necessary for installation or construction of remedial actions. These include costs for:
- Remedial action construction
- Component equipment
- Land and site development
- Buildings and services
- Relocation of affected population where appropriate

Indirect capital costs consist of engineering, financial, supervision and other services necessary to carry out a remedial action. They are not incurred as part of actual remedial actions but are ancillary to direct or construction costs. Indirect capital costs include costs for design and engineering and contingency allowances.

Operation and maintenance costs are those post-construction/installation costs necessary to ensure continued effectiveness of a remedial action.

The post-construction/installation activities necessary to ensure continued effectiveness of a remedial action may involve the following cost components:

- *Operating Labor*—Includes all wages, salaries, training, overhead and fringe benefits associated with the labor needed for post-construction operations. The user should identify the labor requirements by skill categories for each remedial action alternative.
- *Maintenance Materials and Labor*—Include the costs for labor, parts and other materials required to perform routine maintenance of facilities and equipment associated with a remedial action alternative.
- *Auxiliary Materials and Energy*—Include such items as chemicals and electricity needed for plant operations, water and sewer service and fuel costs.
- *Monitoring Activities*—Include costs of sampling, analysis, maintenance of wells and preparation of reports.
- *Purchased Services*—Include such items as sampling costs, laboratory fees and other professional services for which the need can be predicted.
- *Disposal*—Includes transportation and disposal of any waste materials, such as treatment plant residues generated during the course of a remedial action
- *Administrative Costs*—Include all costs associated with administration of remedial action operation and maintenance not included under other categories such as labor overhead.
- *Insurance, Taxes and License*—Include such items as: liability and sudden and accidental insurance; real estate taxes on purchased land or right-of-way (for non-governmental projects); licensing fees for certain technologies; and permit renewal and reporting costs.
- *Maintenance Reserve and Contingency Costs*—Represent annual payments into escrow funds to cover anticipated replacement or rebuilding of equipment and any large unanticipated O&M costs, respectively (for private lease actions).
- *Other Costs*—Include all other items which do not fit into any of the above categories.

Present Worth Analysis

This section contains guidance on recommended procedures for evaluating costs over the planned lives of remedial action alternatives. Present worth analysis provides a method of evaluating and comparing costs occurring over different time periods by discounting all future expenditures to the present year.

Present worth analysis is the recommended method of evaluating expenditures occurring over different time periods. The costs for different remedial action alternatives can be compared on the basis of a single figure for each alternative by discounting all costs to a common base year. This single figure—the present worth or value of a project—represents the amount of money which, if invested in the initial year of the remedial action and disbursed as needed, would be sufficient to cover all the costs associated with a remedial action. Worksheets are provided in the Manual to ease calculation of present worth for cost-effective analysis.

Cost analysis for Superfund actions should follow current guidelines of the Office of Management and Budget (OMB). OMB Circular No. A-94 (6) specifies that costs in future years should not be escalated to account for general price inflation, except where there is a reasonable basis for predicting differences in the relative escalation of costs (or benefits) associated with the project. Otherwise,

Table 2
Worksheet 7: Summary of Sensitivity Analysis (Example)

period becomes negligible and has little impact on the total present worth of an alternative.

Sensitivity Analysis

Procedures are provided for evaluating the sensitivity of cost figures to changes in assumptions. Table 2 is an example of a worksheet provided to document the sensitivity analysis.

The following factors are recommended for consideration in conducting sensitivity analysis:

- *Effective Life of Remedial Action.* If the remedial action alternative relies on a new technology or a technology that has not been tested over a full demonstration, the analysis should consider the possibility that all or a portion of the technology may need to be replaced during the life of the remedial action. In estimating replacement cost, use base period dollars; do not adjust for inflation.

- *O&M Costs.* O&M costs, if required, are likely to represent a substantial portion of total project cost because they may be repeated each year for as long as 30 yr. The major components of O&M cost should, therefore, be considered for examination in the sensitivity analysis.

- *Duration of Cleanup.* The duration of cleanup, or period of performance, is often a key variable (e.g., in actions that require the operation of treatment systems for a period of time based on monitoring results). Various assumptions about the length of period of performance may be suitable candidates for analysis.

- *Uncertainty Regarding Site Conditions.* Even after the conclusion of a remedial investigation, significant uncertainties may exist regarding the extent of cleanup necessitated by site conditions. Examples are the volume of groundwater to be treated, the number of drums to be excavated, the type of materials present and the treatment disposal options to be used. Various assumptions regarding such parameters may need to be examined.

- *Inflation.* Inflation should not generally be examined under OMB costing guidelines, but it may be considered under two conditions: first, if there is good reason to believe that the future prices of materials or services required by a remedial alternative will increase at a significantly faster or slower rate than the general level of prices in the economy; or second, if the inflation rate for the area in which the site is located can be expected to vary significantly from the national average.

- *Cost of Borrowed Capital.* In private or State actions, the cost of capital may be a major factor in determining the overall cost of a remedial action and may, therefore, be tested in the Sensitivity Analysis.

- *Discount Rate.* When comparing alternatives that have major differences in the mix of O&M and capital costs, determine whether a 5% discount rate changes the relative costs of alternatives.

the analyst should use constant (i.e., base period) dollars. Given the difficulty in forecasting relative price changes over an extended period, such forecasts should not be included as part of F.S. Cost Analysis, except perhaps as part of the sensitivity analysis. OMB currently specifies a discount rate of 10%, which represents "the average rate of return on private investment before taxes and after inflation".

The period over which a remedial action requires maintenance and/or operation (period of performance) is also an important factor in present worth analysis. Remedial action alternatives requiring perpetual care should not be costed beyond 30 yr for the purpose of feasibility analysis. Present worth of costs beyond this

A REVISED COST MANAGEMENT APPROACH FOR SUPERFUND REMOVALS

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INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act gives Federal On-Scene Coordinators (OSCs) authority and a funding base to respond to hazardous substance emergencies that threaten public health and/or the environment. The OSC's primary responsibility at Superfund-financed emergency responses (removals) is to monitor or perform all containment, cleanup and disposal activities necessary to protect public health and the environment. Given that OSCs are responding to environmental emergencies, their responsibilities take an added degree of importance.

However, OSCs' responsibilities go beyond those described above. Removals involve substantial CERCLA funding; they are also under intense public scrutiny. The typical removal costs $150,000 per week of operation. Therefore, OSCs must be effective cost managers. In addition, CERCLA requires that reimbursement is sought from responsible parties for all Federal response costs undertaken to implement the Act. Subsequently, OSCs must also document the costs associated with removal actions for purposes of cost recovery.

The purpose of this paper is to propose a state-of-the-art approach to cost management that not only efficiently fulfills the OSCs' cost management objectives, but also aids in improving technical decision-making. The approach is based on the results of a study of current cost control procedures. The proposed approach consists of:
- Defining all costs which must be tracked during a removal action
- Developing mechanisms to track all costs
- Streamlining existing cost management procedures
- Evaluating the use of portable microcomputer systems

OVERVIEW OF REMOVAL COST MANAGEMENT

Goals of Removal Cost Management

OSCs' cost management responsibilities are based on the tenet that cost management goals are most effectively achieved at the removal site. OSCs have three cost management goals at a removal action. The first goal is to track costs for cost control purposes. This goal ensures that cleanup resources are used effectively and efficiently to avoid unnecessary costs. To accomplish this goal, OSCs must identify and coordinate resources available through government agencies and commercial contractors to ensure effective response action, and then track costs to ensure that resources are used effectively and efficiently to avoid unnecessary costs.

The second goal is to estimate costs for cost projection. This goal has two elements. The first element is to ensure accurate calculation of anticipated removal action costs prior to the start of a removal. If this goal is achieved, OSCs will be able to calculate accurate removal cost ceilings. The second element is to ensure an accurate running total of actual expenditures and estimates resources necessary to complete the removal action. Ongoing cost projection, if successful, provides advance warning of any need to increase the removal project cost ceiling. To accomplish this goal, OSCs must project costs to determine initial removal cost-ceilings and then provide advance warning of any need to increase the ceiling.

The third goal of removal cost management is to maintain cost records for cost recovery. This goal requires OSCs to maintain cost records that can serve, when needed, as adequate documentation of expenditures for cost recovery actions against responsible parties. To accomplish this goal, OSCs must maintain accurate, legally defensible cost records to serve as adequate documentation of expenditures for cost recovery actions against responsible parties.

Analysis of Existing Cost Management Approach

The USEPA Emergency Response Division (ERD) is responsible for managing the removal segment of CERCLA's response program. To ensure consistent implementation of cost tracking and cost controls at all removal actions, USEPA-ERD issued the *Cost Control Manual for Superfund Removals* in June, 1982, to provide guidance to OSCs on how to track and control costs at CERCLA removals.

In March, 1983, USEPA-ERD directed the Roy F. Weston Headquarters Technical Assistance Team (TAT) to evaluate the effectiveness of the removal cost tracking and control process since the distribution of the *Cost Control Manual*. The assignment included ascertaining how all participants—in USEPA Headquarters, in the Regions and in the field—currently track and control costs and identifying how cost management procedures may be improved.

In conducting the analysis, TAT interviewed USEPA Headquarters personnel in the Emergency Response Division, Financial Management Division, Procurement and Contracts Management Division, Office of the Inspector General, Office of Waste Programs Enforcement and Office of Enforcement Counsel. TAT also interviewed USEPA Regional ISCs and TATs as well as USCG Strike Team members. In addition, TAT reviewed all applicable guidance and policy documents. Finally, TAT reviewed completed removal action files and conducted removal site visits to observe on-going cost management procedures. Based on the results of this analysis, the USEPA-ERD determined that a more sophisticated cost management system reflecting an evolving removal program is needed for the following reasons:[1]
- New CERCLA cost pollicies have evolved since the *Cost Control Manual* was introduced
- Adequate numbers of personnel often are not available to assist OSCs in carrying out removal cost management assignments
- Cumbersome cost management administrative tasks take too much time to complete, thus detracting personnel from other on-scene responsibilities
- Access is often not available to data that provide OSCs with sufficient technical information prior to determining response mitigation techniques

Table 1
Desirable Field Computer Features

Computer Characteristics	Basis
40 lb Total Weight	Easily transportable; may be carried onto airplane.
Designed for Durability	Must withstand adverse field conditions; dust, smoke, heat and shipment from site to site.
>256K RAM	Ample amount for largest software applications anticipated.
3.5 in. Diskettes	Much more durable than 5.25 in. diskettes; easier to work with, less likely to fail.
8088 or 8086 CPU	Fast microprocessor; IBM compatibility required by OIRM.
MS-DOS	A USEPA-compatible disk operating system for 8088 or 8086 CPUs.
80 Character by 16 Line Screen	Adequate screen size for readability; functional for menu-driven programs, though a larger screen is preferred.
300/1200 Baud Modem	Standard telecommunications speeds.
Plain Paper Printer	Required for enforcement purposes to provide hardcopy documentation of site costs and activities.

Subsequently, USEPA-ERD and TAT are developing a comprehensive approach to removal cost management that should reflect all removal cost elements, ease the administrative burden to OSCs on-site, improve technical decision-making and fulfill the goals of cost management.

Proposed Cost Management System

The cost management system incorporates two main functions:[2]
- Planning prior to actual removal action
- Monitoring on-scene contractors and Federal, State and local agencies providing services once removal action work has begun

OSCs going to the field should have a management plan ready to implement. Preparation of this management plan begins well in advance of any removal action. OSCs must be able to identify and coordinate the resources available to him/her through response agencies and commercial contractors and develop cost information through both general preplanning and incident-specific planning. Planning is accomplished well in advance of any removal and includes the following tasks:
- Becoming familiar with private contractor abilities to clean up, transport and treat, store or dispose of hazardous substances
- Identifying available support resources
- Developing a generic safety plan
- Analyzing previous USEPA costs associated with hazardous substance response actions
- Preparing incident-specific cost estimates

Once work has begun at a removal, on-site cost management procedures must be carried out and completed in detail. OSCs are responsible for the monitoring of contractors and Federal, State or local agencies providing services to ensure that cleanup objectives and control of on-site spending are achieved. Monitoring on-scene response services is a daily responsibility that includes the following tasks:
- Issuing daily work assignments
- Documenting (using logs and records) personnel, equipment and materials used
- Overseeing cleanup activities
- Reconciling contractor reported costs with OSC records

The revised cost management system builds upon the existing, albeit incomplete, cost control process. Key improvements to the system include mechanisms to ensure tracking of all cost elements that are potentially recoverable from responsible parties and/or are included in the removal project ceiling. For example, where site-specific cost elements cannot be tracked in the field (e.g., USEPA contract laboratory costs), sufficient on-site information is maintained so that these costs can be tracked and accessed elsewhere for purposes of cost recovery.

A cost projection system provides a comprehensive way to predict and track all costs attributed to removal project ceilings. The cost projection system provides an approach for OSCs to estimate the major costs of a removal given the proposed removal action to be taken, length of time and other circumstances. A factor of 15% of the sum of the major costs is added to account for remaining removal costs. Using the same approach, cumulative costs are maintained on a daily basis.

Also, emphasis is placed on using available support resources, to the extent practicable, to oversee cleanup contractor performance. Oversight responsibilities include observing contractor work (on a full-time basis whenever necessary), reporting problems to the OSC and ensuring that contractors adhere to safety protocols. Adequate cleanup contractor oversight may avoid three significant problems: cost overruns, inadequate work and jeopardized worker safety.

Computer Applications At Removals

In order to streamline cost management tasks, the USEPA-ERD and TAT have been conducting an evaluation with the USEPA Environmental Response Team (ERT) to determine the utility of providing OSCs with portable microcomputers to aid in fulfilling removal cost management and technical objectives. The idea to use portable microcomputers at removals evolved because documenting costs is time consuming; much data are generated and duplicated; and accurate records must be maintained. If a cost management system could be computerized efficiently, cost information could be readily prepared, and more time would be available to perform other field duties including monitoring cleanup activities. In addition, the portable microcomputers could be used to access and manipulate technical data that would aid in making competent technical decisions, thus improving the environmental integrity of USEPA response actions and potentially reducing costs.

The evaluation results demonstrated sufficiently that the integral use of portable microcomputers at removals could assist in fulfilling cost management and scientific goals while easing the workload of OSCs and support personnel.[3] The field-based computers and peripherals tailored to remove action needs could simplify storage, computation and dissemination of cost information and other pertinent information, broaden and simplify access to scientific and cost data bases and improve decision-making capabilities of OSCs. As a result, better cost and scientific management could be achieved at removals. At removal actions, computers could be used for:
- Projecting initial and ongoing removal costs
- Automating word processing
- Generating daily cost management records
- Accessing the electronic mail system
- Accessing on-line and proposed scientific data bases such as OHMTADS, removal and remedial case history files and data on hazardous waste transporters and treatment/storage/disposal facilities
- Storing, manipulating and retrieving field-generated scientific data

The USEPA-ERD and USEPA-ERT have evaluated portable microcomputer features which should be considered when selecting computers for removal program field use (Table 1).

CONCLUSIONS

The requirements of an evolving removal program justify the use of state-of-art approaches to removal cost management. The USEPA and TAT are in the process of revising removal cost management procedures. In addition, options to computerize these procedures are also being evaluated. Upon completion of these tasks, field personnel will be trained to use the new cost management system.

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FACTORS INFLUENCING CLEANUP COSTS DURING A SUPERFUND REMOVAL ACTION: A CASE HISTORY

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CHRONOLOGY

While horse back riding on February 2, 1984, Gerry Foreman noticed orangish-green liquid standing in a wide, shallow roadside ditch adjacent to his property in a rural area of Orange County, Texas (Fig. 1). A Texas Department of Water Resources (TDWR) investigator, who was called by the Foreman family, surveyed the ditch and estimated that several thousand gallons of an unknown water solution were in the ditch for approximately one-half mile along State Highway 105. TDWR requested a nearby DuPont Chemical Plant's assistance in identifying the pollutant. Chemists from DuPont took samples of the liquid and by the evening had tentatively identified the contaminant as a 5% solution of sodium chromate or dichromate.

The responsible Federal Agency, the USCG Marine Safety Office in Port Arthur, Texas was notified. The Foreman Road location was within the coastal zone of responsibility given to the Coast Guard under the National Oil and Hazardous Substance Pollution Contingency Plan. In addition, there was a great likelihood of the spill reaching navigable water since the drainage ditch was a tributary of Cow Bayou, a navigable waterway of the United States.

The liquid was evaluated as an illegal dump of sodium chromate. Once the chemical was identified and it was established that the responsible spiller could not be readily identified, the USCG, acting under an emergency removal situation, called in an industrial vacuum service to collect the liquid. CERCLA funds were accessed for emergency response and immediate removal action. Upon close examination, it appeared that at least one tank truck load (approximately 5000 gal) of concentrated sodium dichromate solution had been dumped into the ditch some time earlier (Fig. 2). Evidently, this illegal dump of material had, over a period of several days, moved down the gentle gradient of the ditch for one half mile. Before discovery, an unknown portion of the hazardous material had entered Cow Bayou, a tributary of the Sabine River.

The initial actions were directed toward preventing further runoff of contaminated water. Sand dikes were placed at various locations along the half mile of ditch. Cleanup crews worked continuously, vacuuming the standing contaminated water which contained dichromate compounds in concentrations from 50,000 to 150,000 mg/l. Coast Guard personnel monitored the removal, supervising the work and providing waste control manifests for disposal of the liquids at Chemical Waste Management's West Port Arthur, Texas landfill, 25 miles distant.

Water Removal

By Feb. 4, 20,000 gal of contaminated water had been removed. A slow drizzle of rain had hampered cleanup and increased the amount of water requiring disposal. In addition, an elevated water supply canal bisecting the site contributed a constant influx of water. Low spots of an adjacent pasture were saturated with water. It was feared these areas were contaminated or would become contaminated with further rain.

Under these adverse conditions, enough water was removed by the next day so that contaminated soil, although saturated, could be excavated. Vacuuming of contaminated water was stopped. The low lying pastures were fenced and, at the request of the OSC, state health officials were called in to take milk samples from cows in an adjacent pasture. Bulk solid waste trucks were leased by the contractor to haul the soil that would be excavated. From consultation with the on-scene NOAA Scientific Support Coordinator (SSC) and soil chemists from the Research Planning Institute, a long term and immediate cleanup plan was formulated. (For the duration of on-site activity, the SSC continued to monitor cleanup progress, consulting with outside experts as necessary.) Using the results of initial site sampling, it was decided to remove the top
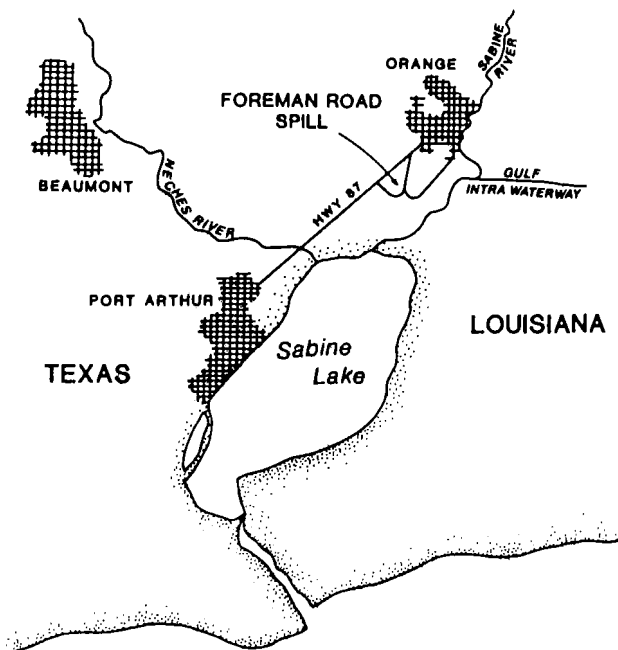
Figure 1
Location of the Spill

18 in. of ditch bottom in the area of highest concentration or the area immediate to where the chemical had apparently been dumped. Once the area of high contamination was removed, soil could be removed more leisurely from the rest of the ditch.

By Feb. 6, 60,600 gal of liquid and 110 yd³ of soil had been removed at a cost of $45,000. The contractor was using a vacuum truck to suck water just ahead of a large mechanical shovel. The shovel was removing the top 18 in. of soil and placing it into lined truck beds for carriage to the disposal site. By Feb. 8, 300 ft of ditch had been cleaned. This area of excavation constituted that portion of the ditch where the liquid pool formed after the dump.

It was apparent from the color of the clay remaining behind after excavation that further excavation was needed. The reason for the vertical penetration of the sodium chromate was at first unclear. Input from soil hydrologists had indicated that chromate solution chromium would migrate vertically through the local Beaumont clay overburden at a rate of approximately 2 ft/yr.

The Rain Comes

On the afternoon of Feb. 9, 4 in. of rain fell in a period of less than 2 hr. Thunderstorms had been predicted, so large sand dikes had been built to prevent runoff. But water from the deluge of rain and runoff from the extensive area drained by the roadside ditch broke through the dike in a matter of minutes.

On Feb. 11, approximately 3 additional inches of rain fell. Response personnel and contractors could do little more than watch as millions of gallons of rain water washed the length of the ditch. On the three following days, the ditch continued to drain the flooded pasture and woodland areas above the drainage ditch. Samples analyzed indicated less than 1 mg/l chromium in the runoff.

Media attention given the apparent illegal dump had heightened public interest. Unrelated cattle and other animal deaths in the area were attributed to the dichromate poisoning. Investigation of the deaths was diverting manpower from the cleanup effort. In an attempt to dispell the concern of local residents, the Center for Disease Control Environmental Health Section was consulted. Local residents were interviewed, and samples of well water and locally produced dairy products were analyzed for chromate. Collective concern for public health in the spill area never materialized. Laboratory tests and statements of health officials were widely publicized in an effort to reassure the public. In addition, the toxicological properties of sodium dichromate were thoroughly explored in daily news releases during the initial days of the cleanup.

On Feb. 15, the ditch was rediked. One sand dike divided the 500 ft of ditch that had been excavated prior to the rains. The dike separated several thousand gallons of rain water from the most contaminated soils. It was soon apparent from the changes in water color that chromate compounds were going into solution from the clay.

Approximately 35,000 gal of rainwater were contained in excavated areas of the ditch. The level of chromate of this water increased from 50 to 600 mg/l in less than 24 hr.

Soil Removal

After dewatering the 500 ft of excavated ditch on Feb. 17, 1984, it was discovered that crayfish burrows had allowed concentrated dichromate solutions to penetrate approximately 4 ft beneath the original ditch bottom. Sodium dichromate solution had entered the burrows and then migrated laterally 6 to 8 in. These cylinders of impregnated clay were apparently responsible for the contamination of thousands of gallons of rain water.

On Feb. 18, an additional 80 yd³ of clay were removed. The crayfish burrows and the surrounding contaminated clay were removed by hand. These burrows occurred on an average of one burrow/4 ft² of ditch bottom; 250 ft of ditch bottom was treated in this manner.

After excavation, the site was capped with crushed shell to maintain the underlying clay in an alkaline condition, encouraging
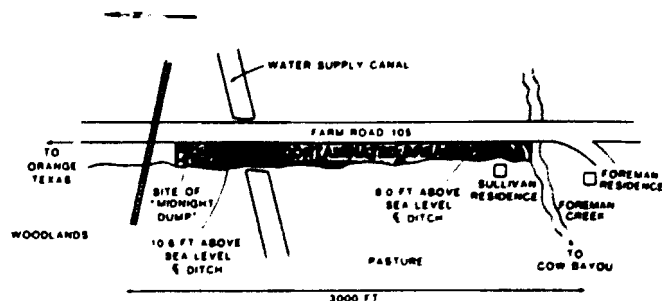
Figure 2
Site Plan of the Spill Area

stabilization of the less hazardous trivalent chromium. A 1 ft layer of clay was packed over the crushed shell to limit surface migration and leaking effects. This buffering and capping was intended to seal remaining chromates in the soil.

Capping the most contaminated area of the ditch completed the most crucial stage of the cleanup. The site was now stabilized. No more rain water would be contaminated. Ninety percent of the sodium dichromate contaminants had been removed. This site stabilization stage took 16 days and required the expenditure of $90,000.

Soil samples taken at regular intervals along the 2500 ft of remaining ditch were found to have from 85 to 300 ppm chromium. It was determined that removing the top 10 in. of soil from this section of ditch would reduce the chromium contamination to the background level of 2 to 3 ppm. Cleaning this portion of the ditch would require the removal of 1200 yd³ of soil at a cost of $120,000. However the operations could wait for the best weather conditions. Excavating 200 ft of ditch bottom per day, the removal of all known contaminated soil was completed on Feb. 29. The ditch was backfilled using spoil supplied by the Texas Highway Department. A small bulldozer was used to restore the gradient and pack the soil.

Soil borings in the ditch and well water were analyzed in April 1984. No samples had chromium levels above background level.

All site activity was completed on Apr. 20, 1984. The total cost of the cleanup, excluding the use of USCG resources, was $218,000. Removed were 105,430 gal of liquid and 1465 yd³ of soil as hazardous waste.

HAZARDS OF SODIUM DICHROMATE

Sodium dichromate is a hexavalent chromium salt ($NA_2Cr_2O_7$). Hexavalent chromium salts are used extensively in metal pickling and plating operations, in anodizing aluminum and in the manufacture of paints, dyes, explosives, ceramics and paper.[1] In the petrochemical and oil refining industry complex surrounding Orange, Texas, sodium dichromate is often used as an additive in cooling towers to inhibit corrosion. It can also be used in drilling muds for high temperature oil exploration.

Hexavalent chromium has carcinogenic potential. Water insoluble (IV) compounds have been assigned a threshold limit value (TLV) of 0.05 mg/m³ by the ACGIH[1]. Water soluble hexavalent chromium compounds have likewise been assigned a TLV of 0.05 mg/m³ although their carcinogenic potential has not been demonstrated. Inhalation of dust will cause respiratory irritation and, in severe cases, nasal septal perforation. Ingestion causes vomiting, diarrhea and, more rarely, stomach and kidney complications. Repeated skin contact will cause dermatitis.[3]

Sodium dichromate is toxic to bluegill fish with a median tolerance limit (TL_m) of 145 mg/l over a 24 hr period in fresh water.[3] Crayfish are much hardier. USCG personnel recovered numerous crayfish at the spill site that had survived in 5 to 10% sodium dichromate solutions for over two weeks with no apparent ill effects. One of the crayfish was analyzed and found to have a total chromium concentration of 0.86 ppm.

USCG officials supervising cleanup operations on Foreman Road dictated that, during the removal of contaminated water, chemical resistant boots, gloves and coveralls be used by all personnel. During soil excavation, when sodium dichromate dust could be generated, approved particulate filters were an additional requirement.

FACTORS INFLUENCING CLEANUP COSTS

It quickly became apparent that the Foreman Road cleanup would be expensive. An initial cost ceiling for superfund expenditures was set at $10,000. Within days after initial response the cost ceiling was boosted to $20,000, then $200,000 and finally $250,000 as the laboratory results revealed the extent of soil contamination.

The Coast Guard On Scene Commander (OSC) also realized that several internal and external factors, some which could be controlled and some which could not, would potentially escalate cleanup costs well beyond the proscribed $250,000 bench mark. The range of costs of the various components of the Foreman Road cleanup are illustrated in Figure 3.

Although mitigation and cleanup of the Orange County, Texas spill were straightforward and uncomplicated, the range of total cleanup costs could have varied greatly. Figure 1 shows this disparity. For example, disposal costs could have been a minimum of $121,000 if all liquids had been deep well injected and weather conditions had remained favorable. A maximum of $173,000 in disposal charges would have accumulated if the various levels of contaminated water had not been segregated or standing water had not been allowed to evaporate during fair weather.

The major economic considerations of the federal response action were selection and use of the cleanup contractor, disposal methods, weather conditions, the methods of excavation and backfill and the sampling program. Each of these economic considerations will be considered in subsequent sections of this paper.

REPRESENTS WHAT WAS ACTUALLY SPENT

HIGH & LOW NUMBERS REPRESENT THE CONCEIVABLE RANGE OF EXPENDITURES IF OTHER VARIABLES THAT AFFECT COST HAD BEEN CONSIDERED OR NEGLECTED
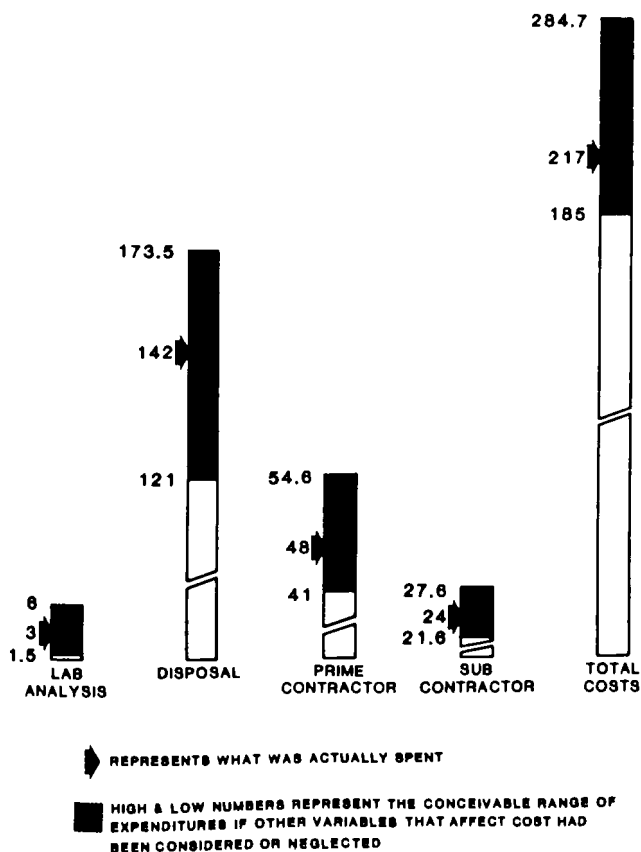
Figure 3
Breakdown of Cleanup Costs at the Orange County, Texas
Sodium Dichromate Spill in $(000)

Secondary economic considerations were use of USCG supervisory personnel, site safety and health, use of on-scene equipment, quantitive analytical techniques, public concern and media attention.

SELECTION AND USE OF THE CLEANUP CONTRACTOR

The Port Arthur Marine Safety Office did not have a contract with a firm for hazardous material cleanup and disposal. In the hours immediately following discovery of the spill, the USCG turned to its federal oil pollution cleanup contractor. This company, an industrial vacuum service, had been awarded a competitive bid contract to cleanup oil pollution occurring in navigable waters of the United States where the source was either unknown or the spiller refused responsibility for cleanup.

Given the requirements of the Foreman Road cleanup, this vacuum service worked well. Removing standing contaminated water, excavation, soil disposal, backfill and grading were easily accomplished by the contractor's personnel and subcontractors.

Two days into the cleanup, the USCG invited two other companies specializing in hazardous material removal to visit the site and bid on finishing the cleanup. Both firms declined to bid on the project, realizing that they could do little more than the contractor already on-site.

Through previous work in oil pollution cleanup, the MSO had developed confidence and trust in the abilities of the contractor. However, if the pollutant had had other hazardous properties in addition to moderate toxicity, major obstacles would have had to be dealt with. The contractor did not have the pumping and containment systems for corrosive and highly flammable substances. Personnel did not have protective equipment or training in hazardous material site safety. If the contaminate had the toxicity of, for example, arsenic trichloride or tetraethyl lead, the government's oil pollution contractor could not have been safely employed.

Financially, using the government's cleanup contractor worked to the MSO's advantage. The oil pollution cleanup Basic Ordering Agreement (BOA) that the vacuum service was under was not valid for sodium dichromate removal. Another contract had to be written. But, because the contractor had been on-site for several days before the contract could be finalized, the solicitation could be written "job specific" and thus avoid the inventory requirements typical of a contract written to cover response for a variety of chemical spills. Contractual mandates for existing inventories of specialized response equipment usually escalate rates for cleanup. However, one disadvantage of a contract written for a cleanup company already on-site is it will not undergo the competitive bid process. Services were rendered at the going rate and did not include reductions in equipment and personnel costs that would be expected from the low bidder. Moreover, government contracts normally restrict or eliminate overtime and subcontracting service charges. This type of financial curtailment, of course, could not be levied on a contractor already working for the government under good faith and in the midst of stabilizing an uncontrolled waste site.

It would be difficult to determine whether money could have been saved if the USCG had a contract with a hazardous material cleanup company prior to the Foreman Road incident. As mentioned, this hazardous waste required neither specialized equipment nor protective clothing. An oil pollution cleanup contractor easily performed the necessary work. But in the long run, over a series of federal hazardous material emergency response actions, it undoubtedly is in the best interests of the taxpayer to award a competitive bid contract to a cleanup service.

DISPOSAL

The disposal of chromate contaminated water and soil amounted to 74% of the total cost of the Foreman Road cleanup. Of the $160,665 spent on disposal, only $34,473 or 16% of the total bill was spent on transportation of waste from the spill site to the dis-

posal site. So approximately $126,000 was expended for disposal. Since the only hazardous property of the contaminated material was its moderate toxicity, the preparation of the waste for disposal centered around its physical properties, especially density, rather than chemical properties like flammability or reactivity.

Hazardous waste arrived at Chemical Waste Management's Port Arthur disposal site as either contaminated water or soil. If the liquid contained a minimum amount of suspended solids, it was deep well injected for 18¢/gal. Water requiring pH adjustment increased deep well injection costs to 25¢/gal. It was determined sodium chromate solution required no pH adjustment. Soil which, on arrival, could be placed in the landfill and support the movement of heavy equipment could be accepted for a minimum cost of $33/yd³. If solidification was required, the cost rose to a maximum of $58/yd³.

During the initial days of cleanup when the site was unstable, the primary consideration was to remove the material in the most rapid manner to the waste receiving facility. USCG officials and the contractor incorrectly assumed that there would be little variation in disposal cost as a result of the physical state of the material, assuming instead that quantity was all that mattered.

Little attention was initially paid to the method of disposal. During the first days of cleanup, several vacuum truck loads of contaminated water were designated for the landfill rather than deep well injection. As a result, several thousands gallons of liquid which were likely suitable for deep well injection were dewatered with kilndust for 45¢/gal. This action precluded the government from realizing reduced disposal costs through deep well injection. This example clearly illustrates the importance of knowing the capabilities and procedures of the nearest waste disposal facilities before they are needed in an emergency.

Once the MSO personnel realized that money would be saved by sending the landfill as clear a liquid or as dry a dirt as possible, officials began to consider ways and means of preparing the hazardous material on-site. Two basic procedures were immediately implemented to save money. Standing water was vacuumed, with precautions taken to skim water off the surface, away from the muddy bottom to keep out as many suspended solids as possible. The weather was closely watched, and when several days of clear weather were predicted sections of the ditch were left to dry. Small drainage ditches were cut to aid the drying. This, of course, prolonged the cleanup, but once the site was stabilized expediency became less of a priority than economy.

As excavation progressed down the ditch, various experiments were tried to hold down cleanup costs. A proposal considered was to stockpile contaminated soil and allow it to drain and dry. The thoroughly dry outer layer of soil could be removed for disposal, much like the peeling of the layers of an onion. This proposal would have brought costs down to the $33/yd³ minimum disposal cost.

The necessity of piling the contaminated dirt on uncontaminated property was the obstacle to this proposal. It was calculated that additional labor costs might outrun the disposal cost savings. Solidification on-site was also considered. However, this process only duplicated what Chemical Waste Management could do at its facility. In addition, it contributed to the volume of material before it was measured for billing.

In the end, the most economical procedures were the simplest —allowing the earth to dry in fair weather and insuring the disposal facility received the cleanest liquid possible.

WEATHER CONDITIONS

As noted earlier, heavy sporadic rainfall disrupted cleanup operations and created more hazardous material that required disposal. Concentrated (5% to 7%) solutions of sodium chromate seeping through the clay via crayfish burrows contaminated rain water collecting over the 100 yd² area of roadside ditch where the material was originally dumped. During a deluge of rain on Feb. 9, 35,000 gal of rain water were contaminated by sodium chromate coming from crayfish burrows.

Standing water under this area was removed, and the most contaminated soils were re-excavated or capped with shell and clay. Once the site was stabilized, USCG officials were reluctant to haul off all the standing water as hazardous waste. Since on Feb. 9, the extended forecast gave 4 days of clear weather, the OSC decided to construct a series of large earthen dams along the ditch. These dikes would hold water of various degrees of contamination. It was hoped that extended fair weather would allow the evaporation of thousands of gallons of water, concentrate the solution and decrease the quantity of waste requiring disposal.

It was calculated that for every week of fair weather in which standing water in the ditch was allowed to evaporate, 0.7 gal of water per square foot of water surface would be lost to the atmosphere. Thus 22,000 gal of water per week could be expected to evaporate over the most contaminated portions of the ditch and 84,000 gal overall for the entire length of the ditch.

SAMPLING PROGRAM

Sampling was conducted with two objectives in mind. Primarily, sampling would determine the extent of contamination of ground and water. Secondly, subsequent sampling would determine the progress of the cleanup. It was found that the more samples taken the less soil and water were removed. Since laboratory analysis costs represented only 1.4% of the total cleanup bill, liberal sampling was an excellent investment.

Of course, for this type of cleanup, sampling is a good investment only if sample analysis is both inexpensive and expeditious. To identify laboratory procedures that were both economical and expedient, it was necessary to determine what needed analysis. In this case, what needed analysis was that substance which was hazardous. Sodium dichromate could be analyzed by local laboratories using atomic absorption spectroscopy for about $50/sample. However, since chromium in its elemental state was the toxic substance, a simple analysis for chromium in its free state would be faster and cost about $22.

Sampling followed a logical sequence. Water and soil samples from above the waste site were analyzed. These samples set the background level of chromium for the area at 3.5 ppm. At and below the chemical dump, a sampling grid was constructed to define the boundaries of contamination. Gradient maps supplied by the Texas Highway Department were used to chart the extent of contamination and the progress of the cleanup.

DuPont put together a simple field test kit that could determine the presence of chromium ions down to a concentration of 100 mg/l ± 30%. This colorimetric test involved simply dropping silver nitrate solution on a water sample. A reddish brown precipitate indicated the presence of chromium. This kit was used very effectively the first few days of cleanup to identify and isolate gross areas of contamination.

CONCLUSIONS

The February 1984 Foreman Road cleanup was the first CERCLA-funded cleanup for MSO, USCG Port Arthur, Texas and it was the first CERCLA-funded emergency removal action taken by the USCG on the Gulf Coast. A lack of experience in this type of activity caused some mistakes in the initial days of the cleanup. However, the interest of the MSO Commanding Officer (who was the OSC), immediate input from the Scientific Support Coordinator and the hours of on-scene supervision by USCG Petty Officers and Officers contributed to significant conservation of cleanup funds. In conclusion, the authors have composed a list of questions which may be used by the novice to evaluate the economy of hazardous materials cleanups:

Before a Cleanup

- What are the capabilities of the nearest waste disposal facility? What is the least expensive disposal method available?
- Is there a representative of the waste disposal facility who, in an emergency, can assist you in calculating the cost of various dis-

posal options? Does this person have the technical expertise to assist you or the cleanup contractor in preparing waste for economic disposal?

• Have you identified a hazardous material cleanup contractor in your area? Do you have a contract with them? Would a competitive bid contract be appropriate?

During a Cleanup

• Have you invited other cleanup firms to the site to offer a bid? Have you at least discussed the cleanup with other firms? Do you have alternative methods of cleanup?

• What local industries can help you? Can they provide quantitive analysis?

• Are you regularly reconsidering the effectiveness of cleanup and disposal methods?

• Are you consulting with the contractor and a waste disposal facility regularly?

• Will adverse weather conditions ruin cleanup efforts? Can you afford to wait for better weather?

• Have you consulted USEPA and other appropriate governmental agencies, not just initially but at regular intervals for the entire cleanup?

• Is media attention and public concern making you do more work than is necessary? Are you talking to the press regularly to keep them updated and help alleviate unreasonable concerns in the community?

DISCLAIMER

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the U.S. Coast Guard or National Oceanic and Atmospheric Administration.

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STATISTICAL CONSIDERATIONS IN GROUNDWATER MONITORING

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INTRODUCTION

This paper examines statistical aspects of obtaining groundwater samples from monitoring wells at hazardous waste sites and analysis of the chemical concentration data. Ever since the promulgation of the requirements by the USEPA in the 1970s for monitoring groundwater quality at hazardous waste sites, there has been uncertainty in how to interpret the monitoring data obtained and how to ensure high quality data.

There are several versions of statistical tests proposed for use in determining groundwater contamination. The use of these methods, however, has been reported to cause high rates of false positives.

The emphasis in this paper will be on systematic methods of analyzing the above data using statistical methods. The analysis of the problems is not approached from the viewpoint of evaluating the performance of indicator parameters used in detecting some type of change in groundwater quality but from the viewpoint of understanding variability relevant to groundwater monitoring. To improve the reader's background on analyzing variability, the paper begins by introducing some statistical concepts via an example for separating variability associated with groundwater monitoring. A simple procedure illustrated will test for differences among concentrations of upgradient and downgradient wells.

Background of Groundwater Monitoring

Presently, the Federal regulations promulgated under the requirements of RCRA specify the use of a minimum of one upgradient well and three downgradient wells to detect groundwater contamination at hazardous waste sites. The upgradient well is monitored for one year on a quarterly basis to establish the background concentration of the four indicators. The downgradient concentration obtained from one of the monitoring wells subsequent to the first year monitoring of the background well is compared to the background concentration using Student's t-test or its modification.

One drawback of this approach is the wide ranging variability associated with groundwater monitoring data, which creates problems in performing the t-test. It is generally felt that in order to obtain good quality data and perform a valid statistical test it is necessary to perform additional steps of determining different types of variation affecting groundwater quality.

The results of studies conducted by contractors under contract with the USEPA,[1,4] some industry analysis[2] and available groundwater monitoring data[3] indicate that background concentrations in groundwater vary from season to season, from year to year and from well to well. In addition, it is known that the results of sample analysis vary from sample to sample and analysis to analysis. Although the sources of variance are extremely complex, major groupings are:

- Temporal variation (including between-year and between-season variation) which could possibly be due to unsteady state plume migration and other effects
- Well-to-well variation which has a fixed component and a moving one

- Analytical variation
- Sampling variation

When groundwater is contaminated, the contaminants will be transported downgradient of the area of contamination by groundwater flow. Dispersion and retardation will have an affect of diluting and attenuating the plume concentrations. If the groundwater seepage velocity is small and the upgradient monitoring well is sufficiently close to the hazardous waste site, dispersion propagating in symmetric directions will impact upgradient as well as downgradient wells. The extent of the impact will also be dependent upon the magnitude of dispersivities prevailing in a particular hydrogeologic setting.

The plume concentration, different for different parameters, may move over time or be stationary; moreover, it may be influenced by geologic material and well construction differences. Seasonality may be infiltration related, so dates are less important than rainfall (e.g., inches of rainfall since the last frost of spring) or it may be temperature related. However, complexity as always is only resolved by simplifying assumptions. In this paper, the author has divided variance into four sources, but any of the four could similarly be subdivided.

In a part of this paper, the author discusses in more detail how these variables affect the observed results of groundwater quality and how groundwater contamination can be statistically detected given the variability mentioned above. Before proceeding with the investigation, one could raise several interesting questions. Among those questions would be "How many data points does one need to establish the reliable background concentration of upgradient wells?"

The efficiency of monitoring study can be increased by using statistically designed well-sampling schemes (called designs by statisticians). Engineers are concerned with well-monitoring schemes and the analysis of data. Well sampling combinations should be planned so that all relevant information can be efficiently extracted from the data. The design of a well sampling scheme is more important than analysis, because without a good design, it would not be possible to obtain so much information with the same amount of work. The author begins with some actual examples to illustrate the basic simplicity of well-monitoring design.

The following example, borrowed from the concept of two level factorial designs, shows how 16 well-planned monitoring samples can be used to factor out seasonal and analytical variability and to reach reliable conclusions on groundwater contamination. These 16 monitoring data points represent the two level three variable factorial design. Where illustration is needed, the field data will be used wherever possible. The lack of actual monitoring data hampers illustration based on the field data in certain cases. This is especially true in demonstrating the sampling variability among the four variables.

The examples given below use the field data to demonstrate the well-to-well, seasonal and analytical variability and can be extended to determine the effect of sampling variability. This may not be necessary if the samples are randomly taken and if the objective of the statistical test is only to find the statistically significant increase between the upgradient and monitoring wells. Because of the lack of field data, the examples involving the three variables (well-to-

well, seasonal and analytical) use field data for one level of sampling and hypothetical data for the other level of sampling.

A WELL SAMPLING EXAMPLE

To facilitate understanding of separation of the effect of each variable on the concentration change, a well sampling scheme using a factorial design involving three variables (well-to-well, seasonal and analytical) is used. Two levels of well sampling are used to establish the background concentration. It is assumed that there are two upgradient wells identified as Well #1 and Well #2. These two background wells are sampled at two different seasons, identified as Season #1 and Season #2. For example, Season #1 may correspond to the 2nd quarter.

To study the effect of analytical variability at the two levels, a sample is split into two for analysis. The split samples will be designated as Split # and Split #2. The same approach can be extended to other cases where one upgradient and more than two background wells are used.

Performing all possible combinations of well sampling to accommodate these variability requires $2^3 = 8$ analyses. To increase the precision of the results and to obtain an estimate of random error, these eight sets of monitoring samples can be repeated. Hence, two replicate analyses are performed on each split sample. Thus, in reality, obtaining split samples for analytical variability and replicate analysis of each split sample amounts to performing four replicate analyses on each well sample. However, each replicate analysis is assumed separated from each split sample. This gives 16 data points in all.

Well Sampling Conditions

As described previously, the three factors affecting variability are selected for illustration. These include: (1) well-to-well, (2) seasonal and (3) analytical variability. For each factor, two levels chosen are identified by Level #1 and Level #2. The variability matrix is shown in Table 1.

Table 1
Factors Affecting Data Variability
(two levels of three factors)

Factors	Level 1	Level 2
well-to-well	Upgradient Well #1	Upgradient Well #2
Seasonal	Season #1	Season #2
Analytical	Split #1	Split #2

Samples taken at each level of the three factors are replicated.

Well Monitoring Scheme

Eight sampling includes all combinations of two levels of three factors. The eight combinations of well sampling are given by the eight rows of Table 2.

Table 2
Well Sampling Based on a 2^3 Factorial Design

Test No.	Well-to-Well (#)	Seasonal (#)	Analytical (#)
1	Well 1	Season 1	Split 1
2	Well 2	Season 1	Split 1
3	Well 1	Season 2	Split 1
4	Well 2	Season 2	Split 1
5	Well 1	Season 1	Split 2
6	Well 2	Season 1	Split 2
7	Well 2	Season 1	Split 2
8	Well 2	Season 2	Split 2

Notice that no two rows have the same sampling conditions. This array can be thought of as merely a collection of eight different samples. For example, the actual sampling conditions for Test No. 1 are upgradient of Well #1, Season #1 (or 1st quarter) and Split #1. The experimental conditions for Test No. 6 are upgradient Well #2, Season #1 and Split #2.

Groundwater Monitoring Data

According to the monitoring scheme, the sampling from the upgradient wells can be performed. To duplicate each of the eight samples, a split sample is replicated. This process involves duplicate analysis of a split sample. Since each of the split samples from two different upgradient wells of two different seasons is repeated, 16 data points in all are obtained. The purpose of the replicate analysis is two-fold: (1) to increase the precision of the answers and (2) to provide an estimate of the intrinsic variation in the sampling and analysis method.

Table 3
Analysis Results of Samples from Upgradient Wells

Test No.	Well-to-Well	Seasonal	Analytical	TOX Conc. (ug/l) Ca, Cb	Av.Conc.
1	Well #1	Season #1	Split #1	43, 42	42.5
2	Well #2	Season #1	Split #1	46, 32	39
3	Well #1	Season #2	Split #1	34, 29	31.5
4	Well #2	Season #2	Split #1	33, 27	30
5	Well #1	Season #1	Split #2	43, 25	34
6	Well #2	Season #1	Split #2	35, 36	35.5
7	Well #1	Season #2	Split #2	27, 27	27
8	Well #2	Season #2	Split #2	37, 28	32.5

Table 4
Analysis Results of Samples from Downgradient Well

Season	TOX Conc. (μg/l)
Season #1	1200
Season #2	1000

Sixteen observed values of groundwater sample analysis for TOX are given in Table 3. The data were retrieved from STORET and are the actual field monitoring data taken on May 19, 1982, and Aug. 12, 1982 for Season #1 and Season #2 samples, respectively. The last column of the table shows the average concentration of the replicate analysis for each of the eight distinct well samples.

Analytical results of samples taken at two different seasons from a downgradient well were also retrieved from STORET and are shown in Table 4. These data will be used for a statistical test later.

So far, the sampling variability has not been considered. The reason for deferring the inclusion of the sampling variability relates to its difficulty in representing the affect of the four variables. Another reason for not discussing it earlier is the unavailability of the field data taken at different levels of design for the sampling variability. The different levels of sampling are represented as Sample #1 and Sample #2. All conditions of data variability can be written down as a combination of the two levels of the four variables.

The 16 distinct combinations of the sampling conditions are given by the 16 rows in Table 5. This array in Table 5 can be thought of as merely a collection of 16 different test conditions for obtaining groundwater monitoring data. For example, the actual conditions for Test No. 1 are Well #1, Season #1 and Split #1 from Sample #1. Similarly, the test conditions for Test No. 7 are Well #1, Season #2 and Split #2 from Sample #1. Since all the test conditions are repeated, the well monitoring combinations for the four variables generate 32 data points in all.

Table 5
Well Monitoring Combinations for Four Variables

Test	Well-to-Well	Seasonal	Analytical	Sampling	TOX Conc, (ug/l) C_a	C_b	Av. Conc.
1	Well #1	Season #1	Split #1	Sample #1	43	42	42.5
2	Well #2	Season #1	Split #1	Sample #1	46	32	39
3	Well #1	Season #2	Split #1	Sample #1	34	29	31.5
4	Well #2	Season #2	Split #1	Sample #1	33	27	30
5	Well #1	Season #1	Split #2	Sample #1	43	25	34
6	Well #2	Season #1	Split #2	Sample #1	35	36	35.5
7	Well #1	Season #2	Split #2	Sample #1	27	27	27
8	Well #2	Season #2	Split #2	Sample #1	37	28	32.5
9	Well #1	Season #1	Split #1	Sample #2	40	41	40.5
10	Well #2	Season #1	Split #1	Sample #2	47	31	39
11	Well #1	Season #2	Split #1	Sample #2	36	34	1.
12	Well #2	Season #2	Split #1	Sample #2	33	29	11
13	Well #1	Season #1	Split #2	Sample #2	45	30	37.5
14	Well #2	Season #1	Split #2	Sample #2	30	31	30.5
15	Well #1	Season #2	Split #2	Sample #2	29	27	28
16	Well #2	Season #2	Split #2	Sample #2	37	37	37

Analysis of the Analytical Variability

It is now appropriate to investigate the significance of the analytical variability. To design two levels of data collection for the analytical variability, a sample taken at different levels of the well-to-well and seasonal variation is split into two for analysis. Also, recall that a split sample is analyzed twice to increase the precision and to provide the intrinsic variability in the groundwater monitoring method. In actuality, this requirement resulted in analyzing a groundwater sample taken from an upgradient well in four replicates.

For example, Test No. 1 and Test No. 5 use the same sample obtained from Well #1, Season #1 and Sample #1. But they are split into two, and replicated in analysis. The similar argument can be made for Test No. 2 and Test No. 6, etc. The effect of the analytical variability on the results of groundwater monitoring data is nothing more than an estimate of random error one is trying to determine as the intrinsic variability. Hence, the analytical variability can be included as part of the intrinsic variability in the groundwater monitoring method. It follows that one can investigate the effect of the three variables instead of four, treating the analytical variability as part of the intrinsic variability.

The three variables of concern are the well-to-well, seasonal and sampling variabilities. If one is concerned with the effect of analytical variability, a sampling design can be constructed according to the levels shown in Table 5. However, if the analytical variability is treated as part of the intrinsic variability, the well monitoring combinations will be reduced to eight distinct test conditions.

The use of the data in Table 5 for the eight test conditions will yield four replicate analyses for a sample. That many replicates may not be necessary to provide an estimate of the intrinsic variability. Two replicates are sufficient for this purpose.

Hence, the well monitoring scheme based on two levels of the three variables with two replicates will yield 16 data points in all.

Average Variabilty Effects

All possible combinations of two levels of three variables requiring eight well samples are shown in Table 6. The table also shows the actual monitoring data for Tests No. 1 to 4 and the hypothetical test data for Tests No. 5 to 8.

Effect of the Well-to-Well Variability

When concentrations between two upgradient wells monitored at the same time are compared, there could be a significant change in concentration because of the well-to-well and sampling variability. This variability, in the absence of contamination, may be explained by a different mechanism than occurs in the presence of contamination. How would one consider this well-to-well variation and evaluate its influence on the change of concentration between the upgradient and downgradient wells in the process of statistical comparison?

Before answering this question, one should investigate the range of concentration change between two different wells in the absence of contamination.

One should note that the sampling and seasonal conditions for Test No. 1 and Test No. 2 are the same, but the samples are obtained from different wells. Well #1 is used for Test No. 1 and Well #2 is used for Test No. 2. Therefore, the difference of concentration in this pair of tests, apart from intrinsic variability present, can be attributed solely to the effect of the well-to-well variation alone. Similarly, for the pairs of Tests No. 3 and 4, 5 and 6, and 7 and 8, each pair involves similar sampling conditions with respect to the sample and season, but different sampling conditions with respect to wells. Thus the difference between each pair of the results reflects the effect of the well-to-well variability alone.

The differences of concentration for the example shown are $-3.5(= 39 - 42.5)$, $-1.5(= 30 - 31.5)$, $-1.5(= 39 - 40.5)$ and $-4(= 31 = 35)$. The overall average effect of the well-to-well variation, Ew, is the average of all four differences:

$$E_w = \frac{-3.5 - 1.5 - 1.5 - 4.5}{4} = -2.75 \text{ ug/l} \tag{1}$$

The formula for calculating the average effect of the well-to-well variability is:

$$E_w = \frac{1}{4} \{C_2 - C_1 + C_4 - C_3 + C_6 - C_5 + C_8 - C_7\}$$
$$= \frac{1}{4} \{39 - 42.5 + 30 - 31.5 + 39 - 40.5 + 31 - 35\} \tag{2}$$
$$= -2.75 \text{ ug/l}$$

where C_1..., C_8 are the concentrations obtained for Test Nos. 1..., 8 respectively.

The average effect of the well-to-well variability is equivalent to the main effect of the well-to-well variability, a common terminology utilized in the field of factorial designs. The result is the observed effects of the well-to-well variation averaged over all the other combinations of the other variables. It is the effect of changing the well from one to another which results in the change in concentration.

Calculation of Confidence Intervals

If one obtains an answer of 2.75 $\mu g/l$ for the average effect of the well-to-well variation, this means that when measurements are made from one well to another, the concentration has changed by 2.75 $\mu g/l$ on the average in the absence of contamination. It may be that 95% confidence interval is 2.75 ± 0.5, but on the other hand, the confidence interval may be 2.75 ± 50. There is a difference in these two cases.

95% confidence intervals can be determined using the following equation:

$$\text{statistic} \pm t \sqrt{\text{estimated variance of the statistic}} \tag{3}$$

where the value of t is the critical value read from a t-table, and the statistics of interest are the average effect of the well-to-well variation.

The estimated variance of the statistic can be determined from knowledge of the intrinsic variability of the monitoring procedure. As indicated before, if the 95% confidence interval were 2.75 ± 0.5, one would feel that an average variation of concentration between wells is rather convincingly demonstrated, and one would

Table 6
Well Monitoring Combinations for Three Variables

Test No.	Well-to-Well	Seasonal	Sampling	TOX (ug/l) C_a	C_b	Av Con.
1	Well #1	Season #1	Sample #1	43	42	42.5
2	Well #2	Season #1	Sample #1	46	32	39
3	Well #1	Season #2	Sample #1	34	29	31.5
4	Well #2	Season #2	Sample #1	33	27	30
5	Well #1	Season #1	Sample #2	40	41	40.5
6	Well #2	Season #1	Sample #2	47	31	39
7	Well #1	Season #2	Sample #2	36	34	35
8	Well #2	Season #2	Sample #2	33	29	31

assert that the well-to-well variation would be fairly close to 2.75. If the interval were 2.75 ± 50, this would not be the case at all.

To obtain a quantiative measure of the uncertainty in the average effect of the well-to-well variation, one calculates the within-groups mean square by pooling all estimates of a common variance σ^2. Returning to the example in Table 6, one can calculate eight estimates of the variance $s_1^2, s_2^2, ---, s_8^2$, one for each test. In this example, the degree of freedom $k = 8$ is determined from $k = a = b = c$ (n-1) where a is the number of test for the well-to-well variation, b is the number of test for the seasonal variation, c is the number of test for the sampling variability and n is the number of replicates per cell (n = 2 in the example).

The calculation of s_1^2, the estimate of σ^2 from the two observations under conditions of Test No. 1 can be made as follows:

$$s_1^2 = \frac{(43-42.5)^2 + (42-4.5)^2}{2-1} = 0.5$$

Proceeding in the same way for Tests No. 2, 3lll,8, one gets

insert line that I can't set.

Hence the pooled variance Sp² equals:

$$Sp^2 = \frac{0.5 + 98 + 12.5 + 18 + 0.5 + 128 + 18 + 162}{8} = 54.69$$

Consider a statistic which is a linear combination of the observations, where

$$\text{statistic} = a_1 c_1 + a_2 c_2 + ... + a_n c_n \quad (4)$$

where one has n observations $c_1, c_2, ... c_n$, and a's are constants. The variance of the statistic V(statistics) is given by:

$$V(\text{statistic}) = (a_1^2 + a_n^2)\sigma^2 \quad (5)$$

If the variance of each of the 16 analyses C in Table 6 is σ^2 and the 16 analyses are uncorrelated, V_w, the variance of the average effect of the well-to-well variation is

$$V_w \quad V[\tfrac{1}{8}(c_{2a} + c_{2b} \quad c_{1a} \quad c_{1b} \cdots c_{8a} + c_{8b} - c_{7a} \quad c_{7b})]$$
$$\tfrac{1}{64}(\sigma^2 + \sigma^2 \cdots \sigma^2)$$
$$= \tfrac{16}{64} \quad \sigma^2 \quad (6)$$
$$\tfrac{1}{4} \sigma^2$$

Since the true variance σ^2 is not known, it will have to be replaced by Sp². The t-value for a 95% confidence region based on eight degrees of freedom is 2.306. The estimated variance of the statistic is Sp²/4 or V_w = 54.69/4 = 13.67. Thus the 95% confidence intervals for the well-to-well variation are:

$$2.75 \pm 2.306 \quad \sqrt{13.67}$$
$$= 2.75 \pm 8.526$$

One is 95% confident, therefore, that the average of the well-to-well variation is between -5.776 $\mu g/l$ and 11.276 $\mu g/l$. In other words, it is unlikely that the true well-to-well variation is lower than -5.776 $\mu g/l$ and higher than 11.276 $\mu g/l$.

Determination of Statistically Significant Increase

One uses the data in Tables 4 and 6 to obtain the difference in concentration between the upgradient and monitoring wells. In practice, it is entirely possible that the sampling variation may be included as part of the intrinsic variability. Since no data are available to determine the sampling variability, one can calculate the difference in concentration between the upgradient and monitoring wells based on Sample # 1 and Sample #2.

For Season #1, the concentration difference is

$$1200 - 42.5 = 1157.5, \quad 1200 - 39 = 1161$$
$$1200 - 40.5 = 1159.5, \quad 1200 - 39 = 1161$$

For Season #2, the concentration difference is

$$1000 - 31.5 = 968.5, \quad 1000 - 30 = 970$$
$$1000 - 35 = 965, \quad 1000 - 31 = 969.$$

The average difference in concentration is

$$\frac{1157.5 + 1159.5 + 1161 + 1161 + 986.5 + 965 + 970 + 969}{8} = 1063.4 \ \mu g/l$$

The difference thus determined exceeds the 95% confidence intervals for the well-to-well variation. In addition, the individual difference in concentration between the upgradient and downgradient wells exceeds the effect of the well-to-well variation which lies between -5.776 $\mu g/l$ and 11.276 $\mu g/l$ in the example. Hence, the data show a statistically significant increase.

APPLICATION OF THE METHOD TO OTHER SITUATIONS

The method presented above makes use of the concept of factorial designs and the analysis of variance. The method can be extended to the cases where data are obtained under conditions different than the example. These cases are as follows:

• There are three downgradient wells and one upgradient well. In this case, the well-to-well variance and its confidence intervals will be determined from the three downgradient wells. The confidence intervals will be compared with the difference in concentration between the upgradient and monitoring wells.

• There are one upgradient and three downgradient wells as in the above case, but the quarterly measurement for one year will include the downgradient as well as upgradient wells to establish the background well-to-well variance. Once the well-to-well variance is estimated, the concentration difference between the upgradient and downgradient wells monitored after the facility began operation can be compared as above.

• There are two (or more) upgradient wells and three downgradient wells. Data coveing more than two seasons can be used to increase the accuracy of the results.

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NATURAL RESOURCE RESTORATION/RECLAMATION AT HAZARDOUS WASTE SITES

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INTRODUCTION

The primary emphasis in hazardous waste management has been the protection of human health through site cleanup or site restoration. Restoration to protect ecological health or natural resource values has been given minimal attention. CERCLA addresses "the potential for destruction of sensitive ecosystems" (Section 105) and "injury to, destruction of, or loss of natural resources" (Section 111) and (1) charges federal officials (i.e., Secretaries of Defense, Interior, Agriculture and Commerce) through Executive Order 12316, as trustees for natural resources and (2) designates the USEPA as responsible for assessing such damages and developing action plans for recovery. In this paper, the authors discuss the requirement for natural resource damage and restoration/reclamation assessments of hazardous waste sites and consider the applicability of existing ecological and economic assessment techniques to address damage and restoration/reclamation of hazardous waste sites.

STATUS OF NATURAL RESOURCE DAMAGE ADDESSMENT AND RESTORATION

Estimates of hazardous wastes sites in the United States range from 4,800 to 50,000.[1] By the end of 1983, 539 sites had been classified by the USEPA as Superfund Sites, meaning these sites pose imminent danger to human health and the environment.[2] A nationwide survey[3] to characterize hazardous waste sites has revealed that most of the damage or contamination to ecosystems and other natural resources is due to leachate, leaks or spills. The air, groundwater, surface water and soil are the environmental media most often affected. Of 375 hazardous waste sites surveyed (for which there was sufficient information), 30% had damage to biotic natural resources including flora, fauna and food chains.

Although this survey identified a significant percentage of hazardous waste sites as having or potentially having natural resource damage, neither the 1982 nor the 1983 report of the Council of Environmental Quality Reports mentions natural resource damage as an issue. In the 1982 report, the natural resource sections of CERCLA are not considered major provisions of CERCLA.[4] Recently, the Office of Technology Assessment published its 3-year study on the technology options for managing hazardous wastes, means to address the problem of uncontrolled and abandoned hazardous waste sites and the adequacy of the federal regulatory program. No mention is made in that 400-page document of natural resource damage and the regulatory requirement to address the issue.[1]

Sections 301(c)(1) and (2) of the CERCLA require the federal government to promulgate regulations for the assessment of damages for injury, destruction or loss of natural resources resulting from the release of oil or hazardous substances. These regulations were to be promulgated no later than Dec. 12, 1982. Two types of regulations are specified. Type A regulations are to "specify standard procedures for simplified assessments requiring minimal field observation, including established measures of damages based on units of discharge or release or units of affected area." Type B regulations involve the development of regulations for conducting assessments in individual cases. Specifically, these procedures are to determine the type and the extent of short- and long-term injury, destruction or loss of natural resources. Type B assessments must include replacement value, use value and the ability of the ecosystem or resource to recover. Section 301(c)(3) provides that these regulations be reviewed and revised every two years. To date, no such regulations have been promulgated.

Recently, the USEPA and the Department of Interior (DOI) have become defendants in several law suits regarding natural resource damage and the lack of natural resource damage assessment regulations (e.g., Civil Action No. 84-1668, U.S. District Court for the District of New Jersey). The Department of Interior is currently developing such regulations. On Jan. 10, 1983, the DOI published a public notice in the *Federal Register*[3] indicating its intention to develop such regulations and to request information and suggestions for developing such regulations. On Aug. 1, 1984, the DOI published a second notice to inform the public about the nature of the responses to the first notice.[4] Currently, a work plan for natural resource damage assessment regulations is being developed. A number of the agencies in the DOI (e.g., Bureau of Land Management) are also developing specific policies.

CERCLA also provides for law suits to recover damages to natural resources. Several states have attempted to recover alleged losses to natural resources under CERCLA. This is best exemplified by suits involving Rocky Mountain Arsenal in Denver, Colorado. The State of Colorado has sued the United States, the United States Army, Shell Oil Company and Shell Chemical Company; the United States has, in turn, sued Shell Oil Company.

In the suit brought by the United States against Shell Oil Company, one of the claims for relief states that, "As a result of the releases and threatened releases of Shell's chemicals at the Arsenal, natural resources on, over and under the Arsenal; including air, land, birds, fish, wildlife, biota, lakes and other surface waters; and groundwater, belonging to and held in trust by the Secretary of the Defense, have been and continue to be injured, destroyed

or lost." The Secretary of the Army is conducting an assessment of the damages to such natural resources and currently estimates the amount of such damages to be approximately $1.8 billion, including damages for harm to wildlife and the cost of decontamination of natural resources contaminated with Shell's chemicals.

Stein et al.,[7] in a survey of procedures for determining costs of natural resource damage from oil or hazardous wastes, provide a preliminary view of the status of natural resource damage assessment at the state level. As of 1983, a few states (such as California, Florida and Washington) had attempted to conduct detailed natural resource damage assessments for several hazardous waste sites or spills. Eleven other states have conducted partial evaluations of destroyed or damaged natural resources. Most of these assessments have been associated with oil spills or "fish kill" incidents.

The authors believe that most damage assessments are conducted on an *ad hoc* basis as conditions warrant and agency funds permit. The focus of these assessments has been on highly visible and immediate damages such as direct mortality rather than on consideration of inherent or long-term injury or loss to wildlife habitats or ecosystems. The assessment approaches and procedures used are procedures based on existing oil and water pollution regulations.

The lack of attention to natural resource damage considerations appears to follow a pattern found in man's attempt to control newly perceived pollution problems. The initial efforts are directed at correcting immediate human health concerns (e.g., Love Canal and Times Beach) with secondary attention given to natural resource considerations. Initially, air pollution was seen primarily as a human health problem; however, as the full extent of air pollution effects became understood, both human health and environmental effects were investigated.[8]

NATURAL RESOURCE DAMAGE ASSESSMENT CONSIDERATIONS

Natural resource damage, as set forth in CERCLA Section 101(6), means injury to or loss of natural resources. For hazardous waste sites, the causal agent is a chemical substance which affects the natural resource, rendering it unusable because of possible health effects or causes injury or death to the biotic components of that resource. The types of effects hazardous waste has on natural resources is diagramatically shown in Figure 1.

Basically, hazardous waste will cause both acute and chronic effects to the biotic components of natural resources and will cause contamination of the abiotic components. The contamination of
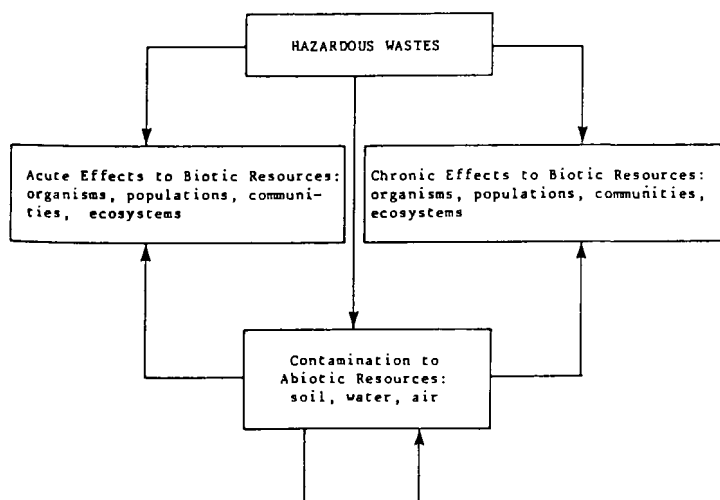
Figure 1
Conceptualized Diagram of the Effects of Hazardous Wastes on
Natural Resources

the abiotic component of the natural resource may cause additional acute and chronic effects to biotic natural resources or further contamination to other abiotic resources. In many cases, acute effects will be short-term.

At the Sapp Battery Superfund site in Florida, an acid waste discharge initially caused death and injury to on-site and off-site wetlands. Fish kills also were reported until the operation was shut down.[9] Chronic effects to natural resources are likely to be the long-term characteristics of hazardous waste sites. At the Sapp Battery site, although the acid discharges have ceased, trace metal contamination of the wetlands and upland areas has continued. Leaching of these trace metals off-site has been observed.

Comments received by the DOI indicate that a definition of natural resource damage is a first priority in developing the proposed regulations.[6] Based on the general policy guidelines of CERCLA, discussions with the Department of Interior and other federal agencies and experience with hazardous waste site evaluations and impact evaluations associated with "classical" pollution problems, natural resource damage assessment can be considered to have three components: (1) affected natural resources and their recognized values, (2) damage assessment and (3) restoration.

AFFECTED NATURAL RESOURCES

Section 101(16) defines natural resources as "land, fish, wildlife, biota, air, water, groundwater, drinking water supplies and other such resources belonging to, managed by, appertaining to or otherwise controlled by the United States (or) any State." This is a broad definition and can be interpreted to include almost everything. Similar definitions were provided in other environmental legislation [e.g., National Environmental Policy Act (NEPA) and the Clean Air Act]. These general definitions are not workable definitions for assessment or management purposes.

Controversies can arise between various interest groups as to whether one or more "natural resources" are important and should be investigated. It is recommended that a general definition of natural resources be developed building on already-defined environmental concepts. It should be applied on a case-by-case basis using already identified natural resources as a starting point for specific damage assessment evaluations.

Since the 1970s, considerable effort has been devoted to identifying important environmental resources at the federal, state and local levels. For example, federal and state wild and scenic rivers have been identified. Federal and state endangered species and their critical habitats are recognized. A national wetland classification system has been developed as well as a system of valuation.[10] Natural resource management plans exist for most governmental land which still has natural environmental features. Federal, state and local land use plans (i.e., coastal management and comprehensive plans) also have sections devoted to natural resource identification. For hazardous waste sites on or adjacent to such lands, identified environmental resources can serve as a basis for developing a list of natural resources for which damage assessment procedures can be applied.

NATURAL RESOURCE DAMAGE

In some ways, the definition of natural resource damage has the same characteristics as NEPA's term "impact." Over the years, the term impact has come to be understood as a significant change from baseline environmental and economic conditions. The environmental impact statement (EIS) literature includes discussions of the meaning of impact or significant impact. Generally, "significant impacts" refer to a man-induced environmental change of large magnitude on a resource and/or a change which affects an important resource.

The authors suggest that, for regulatory purposes, natural resource damage be defined as any significant injury or loss to a natural resource or any significant loss of a natural resource value as established by baseline conditions with the term significant implying the same characteristics as in NEPA (i.e., being of large magnitude and/or involving an important natural resource). Since

human health considerations are paramount, significance should also include any natural resource condition leading to possible human health effects.

The National Oceanic and Atmospheric Administration recently published an economic damage assessment report[11] on the AMOCO CADIZ oil spill. Although the spill was not a hazardous waste spill, the authors recognized the natural resource damage assessment requirements of CERCLA and attempted to relate their experiences for conducting hazardous waste damage assessments. Based on their experience, they identified several general categories of problems associated with natural resource damage assessment, including:

●Uncertainties associated with effects of spills on natural resources, in particular long-term effects of unquantified contamination or unmanifested damage
●Lack of data on preexisting conditions
●The lack of credible methodologies for making damage estimates for noncommercial resources (e.g., seabirds)

Hazardous waste contamination is similar to the "classical" kinds of pollution (e.g., pesticide contamination, oil spills, acid mine drainage and point and nonpoint source air and water pollution). For these and other "classical" kinds of pollution, hundreds of studies, symposia and conferences as well as numerous clean-up, restoration and pollution control programs have been developed, tested and implemented.

Some of the major effects, characteristics, assessment guidelines and regulatory standards for several "classical" pollution problems which are similar to the kinds of problems found at hazardous waste sites are summarized in Table 1. An extensive damage assessment data base has been developed to assess and control these problems. A large number of natural resource agencies have regulatory jurisdiction over these problems and could be a source for applicable assessment techniques.

NATURAL RESOURCE RESTORATION/RECLAMATION

As stated earlier, natural resource damage assessment also includes a requirement for recovery of the damaged natural resource through restoration or reclamation. Recovery includes not only the recovery of a damaged or lost natural resource but also lost natural resource values.

The goal of natural resource recovery is to return the natural resource to the previous or preexisting condition or value. If this goal is not possible, the goal becomes reclamation of the site to an equivalent natural resource condition.

Sustainable recovery programs should be included in the objectives of restoration and reclamation. There should be a definite endpoint to restoration and reclamation so that continued restoration and reclamation practices are not necessary.

Depending on the kind of injury or loss and the costs for restoration and reclamation, the recovery process can be by artificial means (e.g., top soil removal and replacement and revegetation) or natural means using natural ecological processes (e.g., biodegradation) to "clean up" the contamination and to allow natural succession to revegetate the damaged or lost ecological community. Natural recovery rates should also be taken into account. Succession proceeds rapidly in some natural resource systems (i.e., subtropical regions like Florida), whereas in other systems (i.e., deserts and alpine regions) recovery can be slow (e.g., decades to hundreds of years). Numerous restoration/reclamation procedures exist for "classical" pollution problems (Table 1) which are applicable at hazardous waste sites. The choice of restoration/reclamation procedures is a function of four conditions: (1) present condition of the site (i.e., type of natural resources and their values); (2) desired or required recovery rates; (3) desired land use alternatives; and (4) costs for reclamation and restoration. These conditions have to be evaluated on a site-by-site basis.

Table 1
Summary of Selected "Classical" Pollution Problems with Potential Applicability to Natural Resources Damage and Restoration/Reclamation Assessments of Hazardous Waste Sites

Characteristics	Air Pollution	Strip Mining	Oil Spills	Non-Point Source Runoff	Pesticide Application
General Causal Agents	Gaseous, particulate including trace metals and acidifying emissions	Mechanical disturbance and trace metal and acid release	Heavy to light oils	Urban and agricultural runoff—organic and inorganic	Organic and inorganic compounds
Major Reported Natural Resource Effects	Injury and death to flora and fauna; lake acidification	Unproductive soils, injury and death to aquatic organisms, ground and surface water contamination	Injury and mortality of fauna, and fauna, surface water contamination	Surface and ground water contamination, toxicity to aquatic organisms	Toxicity to terrestrial and aquatic organisms, food chain contamination
Most Commonly Affected Natural Resources	Vegetation, soils, lakes	Soil, vegetation, streams, rivers	Aquatic organisms, sediments	Streams, rivers, lakes	Soil, water, sediments
Mitigation Alternatives	Emission control, resistant species	Containment and treatment of wastes	Containment, collection, and disposal of contaminated soils	Source controls—structural and non-structural	Application of controls, reduction/banning
Restoration Reclamation Programs	Lake liming, planting resistant species	Numerous land reclamation procedures, plans required for permits	Natural recovery	Natural recovery dredging	Natural recovery
Representative Regulations	Clean Air Act	Surface mining Control and Reclamation Act; Clean Water Act	Clean Water Act	Clean Water Act	FIFRA; TSCA
Federal Resource Agency Information Sources	NPS, FWS, FS, EPA	BM, FWS, SCS	NOAA, EPA, CG	EPA	USDA, EPA, FS

*NPS — National Park Service.
FWS — Fish and Wildlife Service.
FS — Forest Service.
EPA — U.S. Environmental Protection Agency.

BM — Bureau of Mines.
FIFRA — Federal Insecticide, Fungicide, Rodencide Act.
SCS — Soil Conservation Service.
NRC — Nuclear Regulatory Commission.

NOAA — National Oceanic and Atmospheric Administration.
CG — Coast Guard.
USDA — U.S. Department of Agriculture.
TSCA — Toxic Substance Control Act.

Source: ESE, 1984.

Natural resource restoration/reclamation considerations for two hazardous waste sites are shown in Table 2. At the Sapp Battery site in Florida where cleanup is under way, the conditions are analogous to problems encountered with acid mine drainage from surface mines. Groundwater contamination is continuing. Possible effects on downstream surface waters and aquatic natural resources are uncertain. Restoration has emphasized groundwater restoration.

Although the courts have recognized that liability for natural resource damage includes losses to natural resources (i.e., wetlands and their values), wetland recovery is not a priority in the site restoration plans. Wetland reclamation techniques successfully used in Florida for phosphate mine reclamation are also applicable for the Sapp Battery site.

The Cordova Chemical site in Michigan has characteristics analogous to those found with misuse of agricultural pesticides. In this case, the hazardous waste effects are not as complex; fewer natural resources are affected, and the full extent of the contamination appears to be known. Two restoration/reclamation options were recommended for the Cordova Chemical site: (1) aquifer restoration and (2) no action—allowing natural recovery to occur (an estimated 409 years).

Techniques for aquifer restoration are well established. Relying on natural recovery rates will result in the natural resource (e.g., the stream) and its values being lost for more than a generation. In accordance with CERCLA policies, lost resources and values should be recovered sooner or replaced with equivalent resources and values. In both these cases, several different natural resources

were damaged. Undocumented natural resource damage also is suspected. Restoration and reclamation techniques used to treat similar "classical" pollution problems are applicable to further sites.

In one case (Sapp Battery site), natural resources restoration is not presently being evaluated. At the Cordova site, if natural recovery is allowed, a long-term damage assessment program (i.e., monitoring) may be required.

ECONOMIC CONSIDERATIONS

As previously stated, no specific guidelines exist on the evaluation of economic benefits and costs of natural resource damage and restoration and reclamation assessments at hazardous waste sites. Simplified procedures are requested in CERCLA. Procedures currently used in a few states have attempted to develop replacement values and measure indirect losses and use values. None of the existing procedures meets the needs of CERCLA.[7]

Net Present Worth

A net-present-worth approach is recommended as the primary economic technique to evaluate the monetary costs and benefits of damage and recovery at hazardous waste sites. Nonmonetary costs and benefits are best expressed in appropriate descriptive terms; a six-step process is suggested for an economic evaluation:
- Determine which costs and benefits are applicable to the project
- Obtain project-related data on applicable costs and benefits
- Array those costs and benefits that are nonquantifiable and/or cannot be evaluated monetarily
- Determine dollar value ranges for applicable costs and benefits and value ranges for key economic parameters
- Perform net-present-worth and sensitivity analyses
- Report economic findings

Possible benefit and cost types affected by a hazardous waste site are presented in Column 1 of Table 3. In an economic sense, these types of costs and benefits may be grouped into four categories:
- Those exchanged in well-functioning markets and quantifiable (e.g., restoration/reclamation costs and damage to agricultural crops)
- Those quantifiable and measurable goods/inputs exchanged in less than perfect markets (e.g., public water supply)
- Those quantifiable and measurable goods/inputs that are not normally exchanged in any type of market (e.g., recreation benefit flows from natural areas); because they are quantifiable in some sense, proxies can be used for market values
- Those nonquantifiable and unmeasurable benefits and costs for which dollar values are nearly impossible to determine because of difficulty in quantitative description (e.g., the benefit flow from a scenic view)

Economic Categories

Breaking down benefit and cost types into economic categories provides a sound economic basis to evaluate hazardous waste sites. In performing natural resource economic analyses at hazardous waste sites, it is important to determine dollar value ranges of key input variables and then to perform sensitivity analyses on those variables. Although reasonable dollar values should be obtained for each economic category (e.g., restoration/reclamation costs), dollar values are subject to even greater variability in economic categories 3 and 4, which contain numerous natural resource considerations. Sensitivity analysis allows the economic analyst to vary economic input values and compare the resultant economic impacts. Although oriented to water resource projects, the U.S. Water Resources Council procedures may be useful in determining dollar value ranges.[12]

To properly assess the economic value of any natural resource unit or area (e.g., freshwater marsh), the benefits it provides over an impacted area and over time must be determined. Whereas in the traditional economic market sense, the value of natural resources such as wetlands is primarily a function of its potential for

Table 2
Examples of Natural Resource Restoration/Reclamation Considerations at Selected Hazardous Waste Sites

Characteristics	SAPP Battery Site (Florida)	CORDOVA Chemical Site (Michigan)
Contaminants	Sulfuric acids and trace metals	Organics
Damaged Natural Resources	Known 1. Soils 2. Ground and surface water 3. On- and offsite wetlands 4. Offsite fisheries Potential 1. Upland and on- and offsite wetland wildlife contamination 2. Aquatic food web contamination	Known 1. Soil 2. Ground and surface water 3. Sediment 4. Offsite fisheries Potential 1. Aquatic food web contamination
Damage Natural Resource Values	1. All wetland functions 2. Subsistence and recreational fishing 3. Aesthetic values	1. Recreational fishing 2. Aesthetic values
Similar "Classical" Pollution Problem	Acid drainage from mining	Agricultural pesticides contamination
Restoration/ Reclamation Options	Authorized/Recommended 1. Ground water pumping 2. Collection of soils > 1000ppm contamination Other Possible 1. Artificial restoration of onsite wetlands, allow natural recovery of offsite wetlands.	Authorized/Recommended 1. Aquifer restoration involving ground water pumping and treatment 2. No action—allowing 40 yrs for natural recovery (natural purge options) Other Possible None
Comment	1. Degree of food web contamination unknown, monitoring needed, results could require greater soil decontamination 2. Over $6.5 million for damages to natural resources awarded to State of Florida	1. Ground water plume is moving to surface water stream; no action option should include intensive monitoring of aquatic natural resources.

ppm = parts per million.

Source: ESE, 1984.

Table 3
Benefit/Cost Types, Economic Categories, and Example Analysis Where Evaluated

Benefit/Cost Type	Economic Category	Analysis Where Type Evaluated (X) Exchanged in Markets	Not Exchanged in Markets
Life Cycle Costs			
Feasibility Studies	1	X	X
Land Acquisition/Relocation	1	X	
Construction/Reclamation	1	X	
Operation and Maintenance	1	X	X
Public/Private Buildings	1	X	X
Transportation	1	X	X
Unemployed Resources			
Income	2	X	X
Employment	2	X	X
Tax Revenues	2	X	X
Human Health and Safety	3, 4		X
Water Supply			
Surface Water	2, 3	X	X
Ground Water	2, 3	X	X
Water Quality	2, 3		X
Agriculture	1	X	X
Forestry	1	X	X
Livestock	1	X	
Biotic Communities			
Wetlands	3		X
Uplands	3		X
Wildlife	3, 4		X
Air	3		X
Recreation	3, 4		X
Aesthetics	3, 4		X
Preservation of Environment	3, 4		X

Source: ESE, 1984

development, its best economic use from a CERCLA policy viewpoint may be in its past use where greater benefits were provided to man than are provided in the currently damaged state. There are many service flows from such areas that are not traded in markets. For instance, wetlands may provide wildlife habitat for threatened, endangered and other species and substantial food production sources for fish. Wetlands also interact closely with uplands. As a result, many of these services are joint in nature.

Using the four economic categories, cost-benefit analyses may be conducted to meet the specific characteristics of the hazardous waste site or meet the desires of different groups such as decision-makers or a local interest group. In every circumstance, a life-cycle cost analysis should be conducted. Life-cycle cost analysis involves expressing all significant project costs over a study period for various alternatives in equivalent dollars. Project cost guidelines may be obtained from numerous sources, including the American Society of Civil Engineers, "Manual Number 45—Consulting Engineer".[13] Life-cycle costing techniques also may be found in numerous texts.[14, 15]

Cost-benefit analyses also may be conducted for each economic category inclusive of all previous categories. For instance, an exchanged-in-markets analysis (Table 3, Column 3) would consist of all quantifiable goods/inputs normally exchanged in the U.S. econ-

omy (economic categories 1 and 2, Table 3). Frequently, an analysis for each economic category is not appropriate because the cost and benefit types may overlap the economic categories or certain categories may not exist. The economic analyst should view these economic categories and levels of analysis as evaluation guidelines and evaluate individual sites according to specific characteristics. However, the grouping of types of benefits and costs has been useful to decision-makers because they place their own relative importance on the economic categories.

Economic Parameters

For an economic analysis, economic parameters (i.e., discount rate, study year, study period) must be established. A hazardous waste site will incur costs (i.e., future injury and loss and restoration/reclamation plans) for many years. In order to make sound natural resource damage assessment decisions, monetary values must be identified by amount and time. People generally prefer present benefits to future benefits (e.g., obtaining money now rather than sometime in the distant future) for various reasons. Amounts in different time periods may be put into equivalent, present-worth units by multiplying future amounts by a factor becoming progressively smaller for the more distant time periods. The discount rate is the time rate of decrease in this factor expressed in percent per time period (e.g., 7.0%/yr). The higher the discount rate, the smaller is the discount factor in future time periods. A low discount rate tends to favor alternatives with relatively high benefits and/or low costs in the future relative to alternatives with lower benefits and/or higher costs in the future.

Although not necessary, it is recommended that the economic base year be the year the economic analysis begins. Subsequent present-worth dollar values would be reported in the base year. The study period is the length of time chosen for consideration and study of incremental costs and benefits in the economic analysis. The study period may vary substantially by site and type of project.

CONCLUSIONS

CERCLA specifically requires the protection of natural resources and associated values, as well as assessments of natural resource damage and the restoration/reclamation of injured or lost natural resources. Little emphasis has been given to natural resource damage in most hazardous waste evaluations. The federal government is behind in promulgating natural resource damage assessment regulations. Only a few states have attempted to fully consider the natural damage aspects of hazardous waste sites, although injury and loss to natural resources are documented to occur at a significant number of hazardous waste sites.

A number of problems exist in developing the required regulations including working definitions of natural resources, damage and recovery. Simplified procedures for natural resource damage assessment (including recovery) are also needed. A considerable body of applicable information exists in "classical" pollution literature. This information includes assessment and restoration/reclamation techniques and procedures. This information should be reviewed for its applicability to hazardous waste site assessments and recovery plans.

Natural resource restoration/reclamation should have as its objective the return of natural resources and associated values to their previous or equivalent condition. Both artificial and/or natural recovery procedures can be employed. A comprehensive net-present-worth economic analysis including natural resource effects as project-related life cycle costs (restoration/reclamation) should be performed.

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ASSESSMENT OF GROUNDWATER CONTAMINATION AND REMEDIAL ACTION FOR A HAZARDOUS WASTE FACILITY IN A COAL MINE REGION

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INTRODUCTION

Southwestern Pennsylvania is a region of the country with abundant bituminous coal resources. Historically, these coal deposits, in conjunction with the extensive river system in the Upper Ohio Valley, provided a base for development of a major steel industry.

Coal deposits in the region are flat-lying and have been mined by both underground and open-pit strip methods. The open-pit mines are of interest at the subject site. Coal seams up to 130 ft below the surface are mined today in Pennsylvania by the open-pit method. Dragline excavators with 20 yd^3 capacity are capable of cost-effectively removing rock overburden for coal seams only 5 to 10 ft thick. Present surface mining regulations require that mine operators construct erosion and sediment control and acid drainage treatment facilities and reclaim the open strip cuts to their approximate original surface contour.

Past stripping operations used smaller excavating equipment than modern day draglines, and the depth of the open cuts was limited to 50 to 60 ft. Coal seams were usually stripped along the cropline where overburden was thinner. Parts of the coal seam with greater overburden were deep-mined. Open-pit mines and deep mines were usually both developed at the same coal seam. Many of the older mines were not subject to the regulatory requirements of today. Open-pit mine cuts up to 50 ft deep were left open and unreclaimed. Approximately 440,000 acres in Pennsylvania are classified as unreclaimed mined lands.

Unreclaimed open-pit coal mines provided a convenient location for disposal of a variety of municipal and industrial wastes. Since the mines were in rural, unpopulated areas, they usually had old coal haul roads running to them.

Unreclaimed land was purchased at a low cost by landfill developers and was commonly used for waste disposal. Backfilling of open cuts with wastes was actually seen as an environmental benefit by regulatory agencies because of the restoration of the land surface.

SITE HISTORY AND DESCRIPTION

The site under study is in an area of abandoned open-pit and underground coal mines in Beaver County, Pennsylvania (Fig. 1). The privately owned disposal facility began operations in 1959 as a waste service for the regional steel production and manufacturing industries. Approximately 2 to 8 million gal/month of mostly spent pickle liquors were processed, the majority of which were sulfuric acid. Operations ceased in 1982 under order of the Pennsylvania Department of Environmental Resources (PADER).

Waste types that had been accepted at the facility included corrosives, sludges from electroplating operations, spent stripping
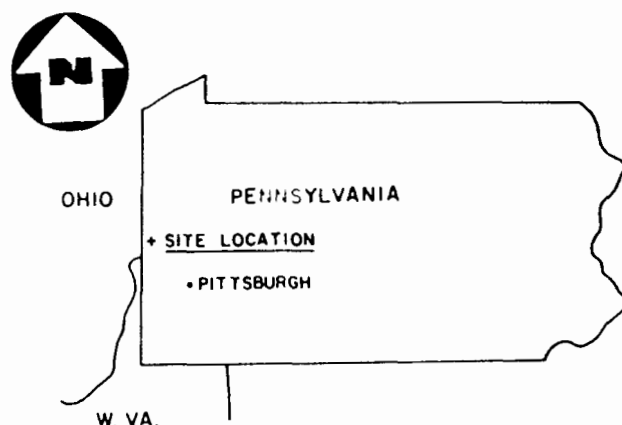
Figure 1
General Site Location

and cleaning bath solutions from electroplating operations, quenching sludges from metal heat treating, spent pickle liquor from steel finishing and sludges resulting from the lime treatment of spent pickle liquors.

The facility (Fig. 2) consisted of a waste receiving, storage and neutralization area and a 45 acre disposal impoundment. The impoundment was constructed in an abandoned stripcut of the Mahoning Coal. Containment of the wastes was achieved by the remnant stripcut highwall and the downslope retaining embankments constructed of local mine spoils. No liners or leachate collection systems were installed.

Raw wastes were received by tank truck and discharged to a lined waste holding tank. The acid composition waste stream was neutralized with a hydrated lime-water slurry to approximate pH 9.5 to 10.0 and discharged to the adjacent sludge disposal impoundment. This is the basic waste treatment process used since 1959. The facility is considered a "Hazardous Waste" landfill because lime-treated wastes are generically listed as "hazardous" under 25 PA Code Section 75.261(h), February, 1981.

For the last 2 years of the facility operations, a portion of the raw waste stream was processed through a waste stabilization pilot plant. The process included addition of various ratios of bentonite clay and Portland Cement to the neutralized wastes.

After treatment by the solidification process, these wastes were rendered "non-hazardous" under a delisting granted by PADER. The solidification operation also had the potential of providing a low permeability cover for the in-place lime sludge. This cover was

evaluated as part of the closure alternatives study and is discussed in a later section of the paper.

The lime-neutralized wastes were discharged into the disposal impoundment and flowed by gravity to the lowest elevations of the impoundment. The solution was a semi-solid slurry of 5 to 10% solids which freely settled and dewatered to a stiff sludge over time. From 50 to 75 ft of sludge are present in the impoundment.
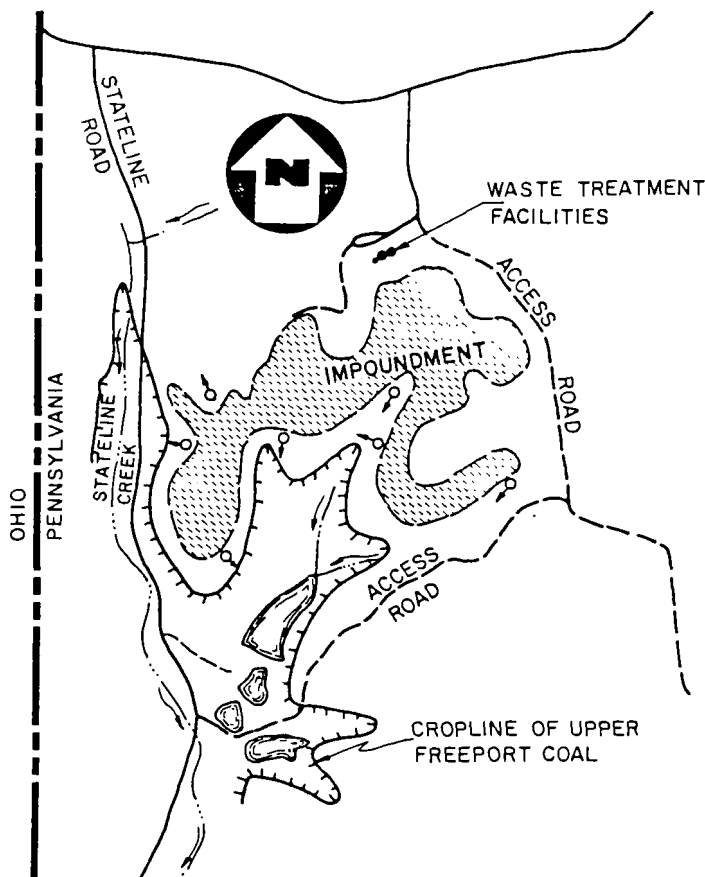
Figure 2
Facility Plan View

WASTE CHARACTERISTICS

Sludge physical properties and chemical leaching characteristics are summarized in Tables 1 and 2, respectively. The sludge is generally a soft, wet, highly plastic silt soil with loose, compressible and sensitive structure. According to the Unified Soil Classification System, the sludge is an MH soil, i.e., a silt of high plasticity. The high plasticity and loose sensitive structure are inferred to result from the chemical composition of the sludge and its mode of deposition. The sludge has low to very low permeability and poor drainage characteristics. Because most of the sludge particles are of silt size, capillarity tends to hold water in the voids between particles, thereby preventing gravity drainage. Capillary effects are also responsible for drying, desiccation and shrinkage of sludge at the pond surfaces. Wet sludge has very low undrained shear strength, while desiccated sludge has moderate undrained shear strength. Under drained loading conditions, wet or dry sludge has high frictional shear strength.

Chemical characteristics shown in Table 2 indicate that contaminants from older sludges and site seepage are similar and are primarily inorganic anions and ammonia nitrogen. Metals are below the USEPA National Interim Primary Drinking Water Standards (NIPDWS). Organic priority pollutants were analyzed for and were not detected at significant levels and are not reported here.

The site seepage has greater concentrations of chemicals than the lime-neutralized sludge leachate. The reasons for the difference

are not clearly understood; however, several hypotheses have been suggested:

- Variations in physical and chemical environment of sludges in situ and sludges in the EP Toxicity Test. Field leaching is at a much less dynamic level than the EP shake test and dilution effects are greater.
- The effects of the coal mine waste materials on the chemical character of the sludge leachate. Mine spoils are acidic and leach sulfuric acid, anions, cations and metals. The reduced pH of the seepage is indicative of the mine waste effects.
- The lime-neutralized sludge samples taken in the field for the EP Toxicity testing have dewatered from approximately 8 to 50% solids, by weight. The free water which was lost prior to taking the sample is probably more indicative of seepage quality than the EP Toxicity leachate.

INVESTIGATION METHODS

Site investigations were conducted in two phases. These investigations included field reconnaissance, test borings, monitoring well installations and groundwater and surface water sampling.

Twenty-seven test borings were made, and 46 observation wells were constructed in the borings with each boring containing from one to three observation wells. Multiple wells were installed at different elevations corresponding to the aquifer interval. Open boreholes were left in the shallow rock aquifers. Permeability

Table 1
Waste Sludge Physical Properties

Waste Gravity of Solids, G_S	3.41
Water Content, w, %	191
Dry Density, lb/ft³	35.7
Atterburg Limits (w, %)	
Liquid, LL	101
Plastic, PL	81
Plasticity Index, Pl	20
Grain Size Distribution	
Sand (larger than 0.074 mm), %	11
Silt (0.074 to 0.002 mm), %	81
Clay (smaller than 0.002 mm), %	20
Permeability, k, cm/sec	3.2×10^{-5}
Consolidation Characteristics	
Initial void ratio, e	7.75
Initial dry unit weight, lb/ft³	24.3
Initial total unit weight, lb/ft³	76.8
Initial saturation ratio, s, %	94
Compression index, C_C	2.67

Table 2
Sludge Chemical Leaching Characteristics and Average Site Seepage Quality

Chemical Parameter	Site Seepage		Lime-Neutralized Sludge	
Barium		0.3		0.2
Cadmium		0.01		0.01
Mercury	<	0.005	<	0.005
Silver		0.04		0.04
Chromium		0.1		0.2
Lead		0.5		0.03
Nickel		1.0		0.1
Chromium (Hex)	<	0.01	<	0.01
Arsenic	<	0.001	<	0.001
Selenium		0.005		0.005
Manganese		6.0		0.02
Zinc		1.0		0.05
Cyanide	<	0.005	<	0.005
Chloride		4,000		50 2,000
Ammonia N		200		5 10
Sulfate		5,000		1,200
Conductivity (umhos/cm)		12,000		1,600
pH (S.U.)		6.5		9.0 9.4

Note: All results are in mg/l. Leachate results are based on an average or range of analyses of extractions from RCRA EP Toxicity Tests.

testing of rosk was conducted at different intervals in open bore-holes during drilling. Twenty-three test pits were excavated to eval-uate soil conditions for a borrow material. Shallow monitoring wells were installed in the selected test pits.

A total of 45 streams and seeps around the site area were sam-pled. Private drinking water supplies within 1 mile of the site were sampled and analyzed for sludge indicators. A total of 21 resi-dences were identified, and monitoring wells were sampled and analyzed for chemicals indicative of the alkaline sludge leachate from the existing disposal site: pH, total dissolved solids, chloride, ammonia-nitrogen and nitrate-nitrogen.

All sampling point locations are shown in Figure 3.

GEOLOGY

The rocks that are exposed in the vicinity of the site belong to two geologic groups. The oldest rocks, the Allegheny Group, are overlain by the Conemaugh Group, both of Pennsylvanian age. The top of the Upper Freeport Coal is the boundary between the Allegheny and the Conemaugh Groups. The rock units are cov-ered by unconsolidated material consisting of mine spoil and glacial deposits.

The entire area of the existing site was covered by glacial de-posits. This deposit occurs alike on hills or valleys as a mantle of silt, clay, sand and boulders. It is distinguished by a heterogen-eous arrangement of this material, although locally it exhibits the effects of sorting by water action. In most of the site area, strip mining for the Upper Freeport and Mahoning Coals has disturbed the mantle of glacial deposits.

A local valley occurs adjacent to the site. It is partially filled with glacial deposits and stream sediments to a depth of 5 to 13 ft. The maximum depth of till material is about 50 ft below the ground sur-face, and its thickness averages from 20 to 30 ft.

The Conemaugh and Allegheny Groups consist of alternating layers of sandstone, siltstone, claystone, limestone and coal. The Conemaugh Group is represented at the site by the Glenshaw Formation. The older Freeport, Kittanning and Clarion Formation represent the Allegheny Group (Fig. 4).

The uppermost rock unit present is the Glenshaw Formation. It has been eroded or removed by strip mining over most of the site. The upper beds at the site are composed of shale and sandy shale which locally becomes sandstone. Below these beds occurs a thin coal seam (Brush Creek Coal) which is about 65 ft above the Mahoning Coal. Between these coal seams occurs a shaley unit with a thick layer of claystone named "The New Galilee Clay Shale." The average thickness of this claystone is 6 ft. It has a characteristic rusty color of orange brown or ochre. This claystone lies from 30 to 43 ft above the Mahoning Coal. A 6-ft thick shale layer sep-arates the Mahoning Sandstone from the Upper Freeport Coal (Fig. 5).

The rock unit between the base of the Mahoning Sandstone and the top of upper Kittanning Coal belongs to the Freeport Forma-tion. The Freeport Formation and the upper portion of the Kit-tanning Formation included the Middle Kittanning Coal and its associated underclay which were extensively studied. The top of the Freeport Formation is defined by the Upper Freeport Coal. The seam has been removed by both deep and strip mining. Where present, it is approximately 3 ft thick. The Freeport rocks and the upper unit of the Kittanning Formation is approximately 140 ft thick. Below the Upper Freeport Coal occurs a continuous fossil-iferous claystone and grey limestone. These rocks are in turn under-lain by a dark shale and siltstone with sandstone layers and the Lower Freeport Coal. The interval between the Upper Freeport Coal and the underlying Lower Freeport Coal, which is predom-inantly shaley, is known as the Butler Sandstone. The thickness of the Butler Sandstone ranges from 50 to 60 ft at the site.

The Lower Freeport claystone (underclay) immediately below the Lower Freeport Coal is about 3 ft thick and grey in color. Below this strata and between it and the next underlying Middle Kit-tanning Coal is an interval primarily filled with dark and black
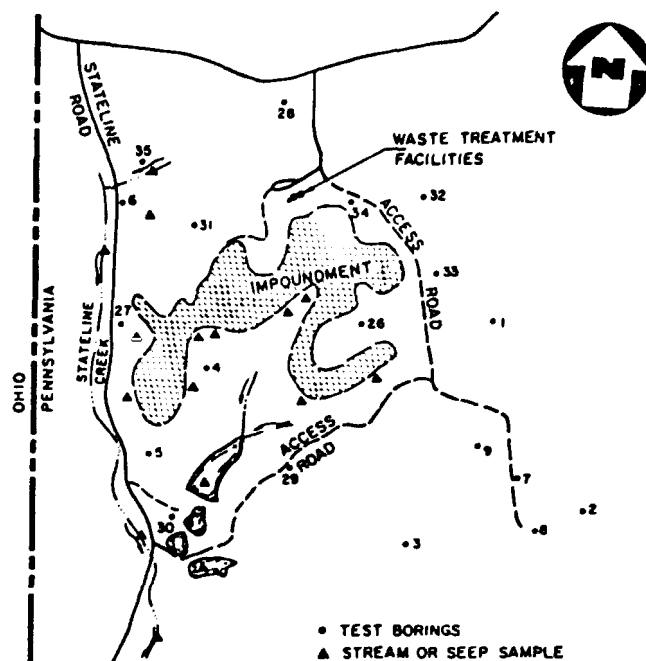
Figure 3
Test Borings & Sampling Point Locations
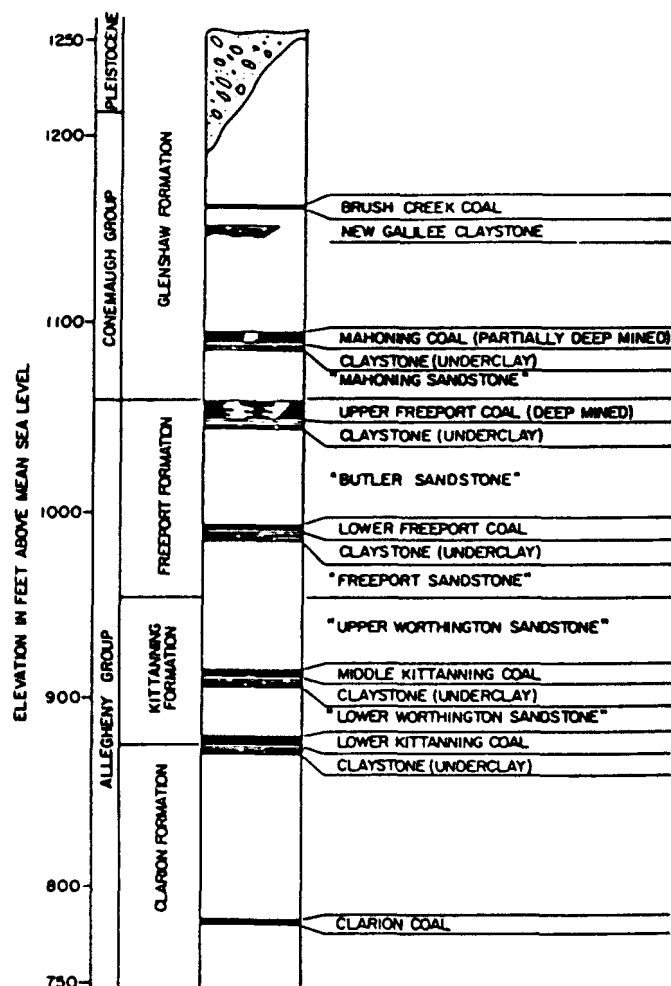
Figure 4
General Stratigraphic Section
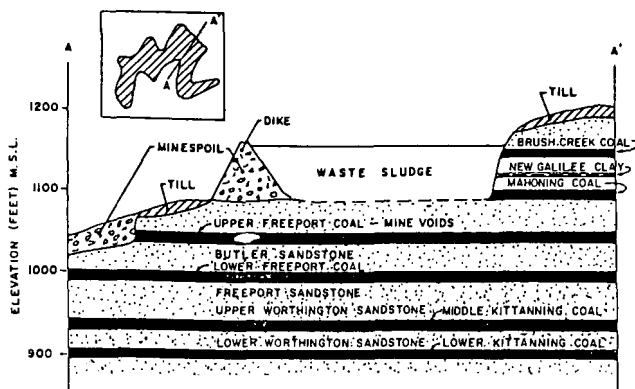
Figure 5
Generalized Geological Cross-Section

shales which are often fossiliferous. The sandstone and siltstone strata occur in this interval.

The Upper Kittanning Coal is not present at the site. The absence of this coal does not allow identification of the separation between the Freeport and Kittanning Formations. The strata overlying the absent Upper Kittanning Coal and Middle Kittanning Coal are known as the Upper Worthington Sandstone. A unit of shale and sandy shale lies between the Middle Kittanning Coal and Lower Kittanning Coal. The base of the Lower Kittanning Coal indicates the Clarion Formation. The shaley and sandy unit is known as Lower Worthington Sandstone.

GROUNDWATER

The interpretation of the groundwater conditions at the existing disposal facility and the vicinity of the site has been based on surface and subsurface mapping data, rate-of-rise tests in bore-holes and groundwater table and seep observations.

Five water-bearing systems have been defined in the study area. These systems include unconsolidated materials, rock strata and abandoned mine workings.

The first aquifer is represented by the shallow groundwater flow systems. These systems occur in the rocks or mine spoil above the Mahoning Underclay and also in the valley glacial deposits below the disposal site. Infiltrated water through the rock strata or mine spoil at higher elevations is perched on the aquifers of the clay-stones or shales above the Mahoning Coal and on the Mahoning Underclay. The perched water table occurs in the area where the underclay is covered by a thick layer of mine spoil or the rocks of the Glenshaw Formation. The groundwater flow is westward.

Perched waters have also been found above the New Galilee Claystone. An average hydraulic head of this perched groundwater is about 15 ft. This water recharges sludges from the Mahoning Coal highwall or migrates downward along the interface between sludge and highwall or mine spoil to the Mahoning Underclay or deeper water-bearing zones.

The shallow groundwater system also occurs in glacial deposits. This shallow aquifer is represented in the valley of an unnamed tributary to Stateline Creek. This aquifer is a glacial deposit consisting of till and outwash material deposited in a typical glacial valley cut into claystone and shales of the Butler Sandstone. This water is affected by the existing sludge and likely recharges the underlying Butler Sandstone and associated rock aquifers. The direction of shallow groundwater flow is southward and reflects the local morphology.

The second principal water-bearing system occurs in the Mahoning Sandstone. This water-bearing system is separated from the perched groundwaters by an impermeable layer of claystone. The water in the Mahoning Sandstone is under a pressure head in the area eastward from the existing site. The Mahoning Sandstone overlies a confining layer of shales which have a thickness of about

5 ft. The discharge area of this aquifer is generally above the out-crop line of Upper Freeport Coal in the valley. The Mahoning Sandstone is probably a leaky aquifer beneath the existing disposal facility and recharges the underlain abandoned mine of Upper Freeport Coal.

The third principal water-bearing zone is the Upper Freeport Coal which underlies the Mahoning Sandstone. This coal has been extensively mined at the site.

Average heaight of rooms was approximately 2.8 ft as dictated by coal thickness. The mine floor consists of the underclay which is the confining bed for the groundwater in the abandoned mine. The thickness of underclay varies from 2 to 18 ft with an average of about 6 ft in most areas. Several seeps discharge at the outcrop line of the Upper Freeport Coal. Seep discharge varies from 1.0 to 1.5 gal/min. The measurement of water tables indicates a few inches of water above the mine floor or lack of water in the monitoring wells located easterly from the disposal facility. The deep mine of Upper Freeport Coal was filled with water in the test borings situated beyond the northern perimeter of the site. Hydraulic head varies from 2 to 4 ft above the mine floor.

Considering the fact that structure and remaining mine voids control the direction of water flow on the base of the Upper Freeport Coal, the larger quantity of water flow should be expected in the area of local structure depression (Figs. 6 and 7). The abandoned mine discharge is observed above Stateline Road (structure depression). Based on the observation of water flow measurement in 1977 and 1978, the average flow was 253 gal/min, with minimum and maximum flows of 183 and 684 gal/min, respectively. The abandoned deep mines under the sludge ponds collect and discharge water which percolates through the overlying sludge. This water is considered leachate.

The fourth principal aquifer at the site represents the Butler Sandstone and associated rocks between the Upper Freeport Coal
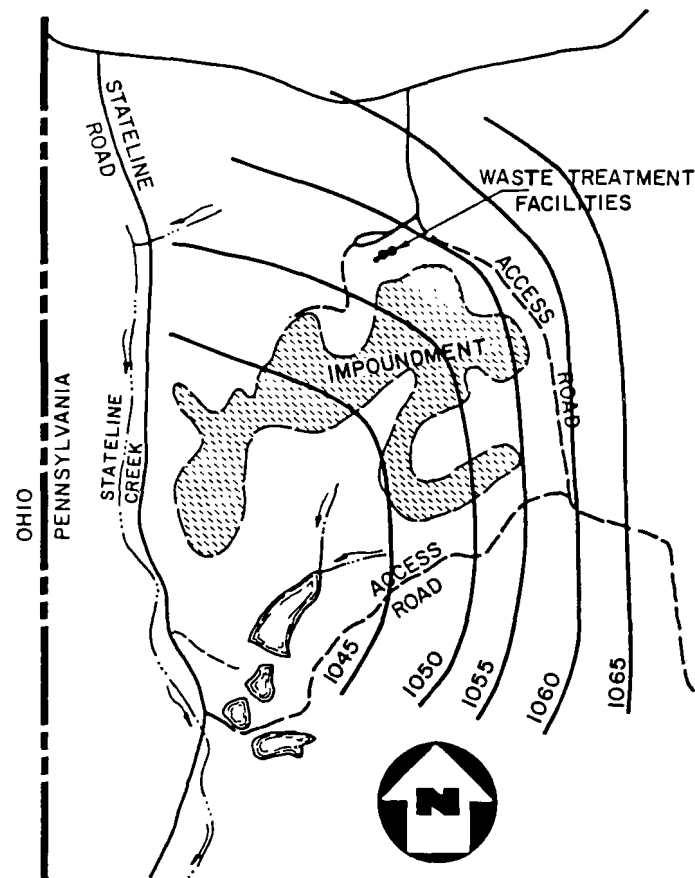
Figure 6
Upper Freeport Coal Structure Contours
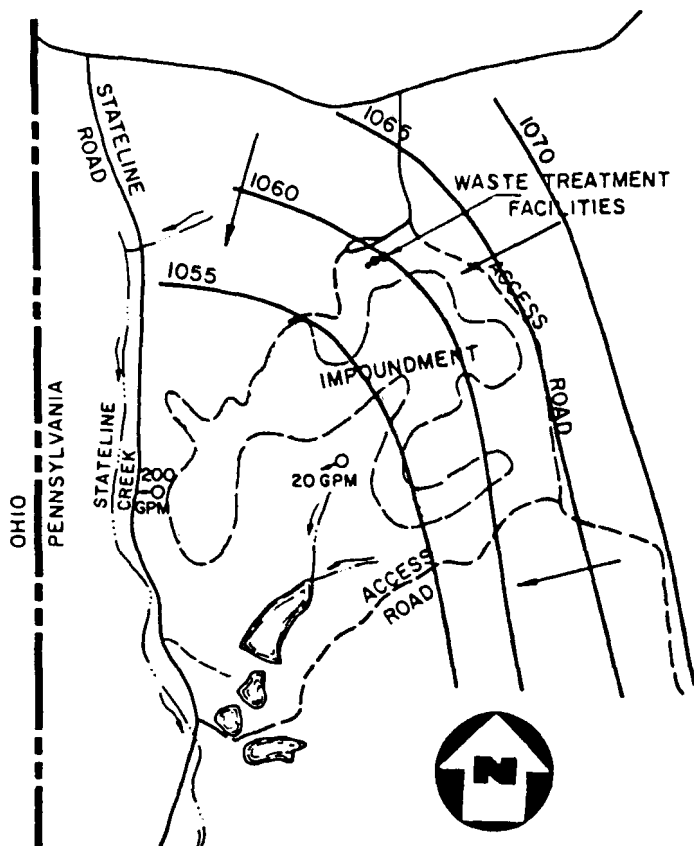
Figure 7
Water Table Contours for Upper Freeport Coal Water-Bearing Zone

and Lower Freeport Coal. Both coals are separated by a confining layer of claystone. This layer has been eroded southward from the site in the area of an unnamed tributary of Stateline Creek and replaced by glacial deposits. The gap in the claystone aquitard is of crucial importance inasmuch as it provides direct access for some volume of recharge from the shallow aquifer to the underlain Butler Sandstone aquifer. Any leachate within the shallow aquifer can migrate directly into the deeper unit upon recharging the window. In this area, groundwater is affected by leachate.

Based on the water level observations, this unit is a semi-confined aquifer. The groundwater flow is southwestward. This aquifer is in the sandstone and fractured shale and siltstone. Lower Freeport Coal also conducts the water flow. The hydraulic conductivity of this aquifer varies from 1.3×10^{-4} to 1.7×10^{-5} cm/sec.

The fifth principal aquifer in this area is the Freeport Sandstone and Upper Worthington Sandstone above the Middle Kittanning Coal. The continuous confining bed of the claystone creates a hydraulic barrier between the overlying Butler Sandstone aquifer and the Freeport water-bearing zone. The thickness of the confining stratum varies from 2 to 12 ft. The groundwater flow direction in the rock strata and Middle Kittanning Coal is westward and reflects exactly the structure of Middle Kittanning Underclay. In general, this water-bearing stratum represents an unconfined aquifer. The water table is only under a little pressure in the area of the local depression structure of Middle Kittanning Coal. The hydraulic conductivities of this aquifer are lower than in the Butler Sandstone aquifer and vary from 8.0×10^{-5} to 2.3×10^{-6} cm/sec. The claystone underlying the Middle Kittanning Coal is the confining bed for this aquifer.

CONTAMINATION AND CONTAMINANT MOVEMENT

Five water-bearing zones were sampled for sludge leachate indicators. Estimates of aquifer discharges and sludge impoundment water balances were performed. Chemical contaminants were con-

sidered to be soluble inorganic species, and conservative transport in groundwater was assumed.

Shallow Unconsolidated Aquifer

This water-bearing zone consists primarily of mine spoils, alluvium and glacial deposits below the sludge impoundment. Analyses indicate that the aquifer is contaminated by leachate in the areas directly south and west of the site. Chloride concentrations range from 13.5 to 3406 mg/l and average approximately 1200 mg/l. No isoconcentration trends are apparent, although a decreasing concentration from the site perimeter is expected. Total nitrogen concentrations range from less than 0.1 to 52.75 mg/l. Average total nitrogen is approximately 12 mg/l. Moderate concentrations (200 to 500 mg/l of chlorides) were found in the alluvium adjacent to Stateline Creek, approximately 2500 to 3500 ft downstream of the major deep mine discharge into Stateline Creek.

This area is probably affected by seepage from the creek bed into the unconsolidated material. Stateline Creek chloride concentrations in this area are slightly higher than the range of chloride in the alluvial test pit wells.

Mahoning Coal Aquifer

Analyses indicate that Wells 31B-1 and 34B are contaminated by sludge leachate. Well 31B-1 has chloride levels from 115 tol 965 mg/l. Total nitrogen concentration is 28.4 to 43.6 mg/l in Well 31B-1 and 0.47 to 19.9 mg/l in Well 34B.

Wells 9-1, 28B and 33 all have chloride levels less than 25 mg/l and total nitrogen levels less than 1 mg/l. These wells are in hydraulically upgradient locations from the site. Wells 31B-1 and 34 are also upgradient of the site; however, their chemical analyses do not reflect their location. Well 34 is 20 ft from the edge of the sludge pond, and although it is "upgradient," it is probably directly influenced by drainage from sludge deposits at higher elevations and dispersion of contaminants from the sludge.

Well 31B-1 is apparently contaminated by the sludge leachates; however, a hydraulic connection between the well and the sludge pond has not been confirmed. Well 31B-1 alone might not be sufficient to characterize the Mahoning Coal aquifer in the approximately 60 acre area northwest of the site.

Upper Freeport Coal Aquifer

Analyses indicate that the deep mine pool on the northwest edge of the site is contaminated by sludge leachate. Well 31B-2 has chloride concentrations of 1200 to 1700 mg/l and total nitrogen concentrations of 29 to 46.1 mg/l. Upgradient wells 8, 28C-1 and 32 had chloride levels less than 21.5 mg/l and total nitrogen levels less than 1.0 mg/l.

Isochloride plots indicate that concentrations decrease with distance from the site as groundwater flows to the west. Well 35A-1, approximately 1000 ft northwest of the site, had chloride levels of 422 and 870 mg/l.

Butler Sandstone Aquifer

Upgradient water quality, as determined from water table contours, is represented by Wells 1A-1, 2-1 and 28C-2. Chloride and total nitrogen concentrations in these wells are less than 6.0 and 6.53 mg/l, respectively.

Analytical data for Wells 4-2, 5B-2, 27-2 and 35A-2 indicate that significant contamination of the Butler Sandstone is occurring. Chloride concentrations in these wells range from 100 to 1500 mg/l and average approximately 965 mg/l. Total nitrogen concentrations in these wells range from 1.66 to 14.6 mg/l.

Isocontours for chloride indicate that contaminant migration is to the northwest and southwest. No data are available beyond the E. Fork of Stateline Creek; however, projections of the chloride isocontours indicate that concentrations greater than 200 mg/l are not expected west of the creek. Increasing chloride concentration trends are present for Wells 4-2, 5B-2 and 27-2. The cause of these trends is not clear based on the available data. The remaining wells exhibit no significant concentration trends.

Since the Stateline Creek drainage has eroded the Upper Butler Sandstone in the site area, discharge of Butler Sandstone groundwater into the Stateline Creek basin is expected.

Freeport Sandstone Aquifer

Upgradient water quality as determined from water table contours is represented by Wells 1A-2, 2-2, 3A-2, 28C-3 and 29A-3. Chloride and total nitrogen concentrations in these wells are less than 95 and 7.9 mg/l, respectively.

Analytical data for Wells 4-3, 5A-2, 5A-3, 6-3, 27-3 and 30-1 indicate that moderate contamination of the Freeport Sandstone is occurring. Chloride concentrations in these wells range from 2.6 to 704 mg/l and average approximately 244 mg/l. Total nitrogen concentrations in these wells range from $<$ 0.1 to 7.8 mg/l.

Isocontours for chloride do not indicate any discernible contaminant migration trends. Comparisons of data from Wells 5A-2 and 30-1 exemplify the inconsistencies in isocontour trends. Wells 30-1, which is approximately 1000 ft downgradient from Well 5A-3, has a higher chloride concentration than 5A-3.

Seepage

Seepage was sampled at 32 locations. Seeps were identified around the perimeter of the facility, mostly on the slopes and at the toe of the sludge impoundment dikes.

Chemical analyses indicate that sludge impoundment seepage has the highest concentrations of leachate indicator parameters of any samples taken in the site area. Chloride concentrations range from 894 to 12,680 mg/l. Average chloride level is approximately 5650 mg/l. Total nitrogen concentrations at these points range from less than 1 mg/l to 460 mg/l.

Embankment seepage and shallow groundwater were found to have the highest concentrations of leachate indicators of all waters analyzed at the site. Upper Freeport Coal deep mine discharges had significantly lower concentrations of indicators, probably because of dilution from upgradient drainage within the deep mine. The two aquifers below the Upper Freeport Coal, the Butler and Freeport Sandstones, have minor concentrations of sludge leachate indicators.

The major groundwater discharge at the site is the Upper Freeport deep mine drainage. Discharge points near Stateline Creek had an average combined flow of 200 gal/min for approximately 2 yr of recording in 1977 and 1978. These flows have been relatively constant over the last 10 yr of observation.

The presence of the extensive deep mine workings in the site area is a positive factor in reducing leakage to the Butler and Freeport Sandstones. The deep mine openings provide an effective freedraining zone that acts as a horizontal groundwater interceptor. Leakage from the Mahoning Sandstone above and from the shallow groundwater system is drained through the mine and discharged. This minimizes the standing water in the deep mine and reduces leakage into the lower Butler Sandstone.

Seepage flowrate from the Mahoning Coal and Sandstone and the sludge pond embankments is significantly less than the deep mine discharge. These discharges have not been accurately measured, but visual estimates of total average flow range from 20 to 50 gal/min.

Estimates were made of the discharge rates of the Butler and Freeport Sandstones into the drainage basin of the E. Fork of Stateline Creek using Darcy's Law. The transmissive area was calculated by multiplying the aquifer saturated thickness by the discharge length. The discharge length into the creek is estimated by the distance between croplines of the aquifer confining units, namely the coal outcrops.

The Butler Sandstone average discharge rate is estimated at 36.4 gal/min. The Freeport Sandstone average discharge rate is estimated at 0.72 gal/min.

A water balance was estimated for the sludge impoundment, both prior to and after final closure. The water balance calculation estimates the amount of liquid inflow to the sludge, which on a steady-state basis equals the liquid outflow, or leachate flow, from the sludge. An annual budget was calculated.

The water balance evaluated the sources of moisture inflow to the sludge. These flows include the lateral groundwater flow from the highwall above the Mahoning Coal and direct precipitation on the sludge surface prior to closure.

A significant difference was estimated for sludge pond inflow for the pre-closure and post-closure periods. Annual average pre-closure inflow is 43 gal/min, and post-closure is 2.37 min. The primary contributor to pre-closure inflow is direct percolation on to the open sludge surface which accounts for an average of 40.6 gal/min, or 95% of the estimated annual inflow. After topsealing of the site, direct percolation is assumed to be zero, and the total annual inflow contribution will be from groundwater. The lateral groundwater inflow contributes 1.25 million gal/yr, or 2.37 gal/min of inflow to the sludge from the Mahoning Coal highwall.

Groundwater inflow is assumed to be present during the pre- and post-closure periods, since topsealing of the sludge pond is not expected to affect the groundwater above the Mahoning Coal.

A summary of the groundwater discharge rates and impoundment water balance is contained on Table 3.

REMEDIAL CLOSURE DESIGN

Site investigation findings determined the extent of contamination and the characteristics of the subsurface drainage system. The objectives of the remedial cleanup were to:
- Reduce contaminant loading on Stateline Creek to acceptable State and Federal discharge levels
- Prevent groundwater contamination of the Freeport Sandstone and lower aquifers

RCRA requirements for closure, post-closure and groundwater monitoring plans were addressed in development of the remedial closure design. These requirements are outlined in the PADER regulations for hazardous waste management (25 PA Code Chapter 75, Nov. 29, 1980).

The remedial concept determined to be the most cost-effective was capping the sludge impoundment and collection and treatment of leachate and contaminated groundwater discharges to Stateline Creek.

A conceptual closure plan is depicted on Figure 8. The sludge impoundment discharge would be significantly reduced by placing a low permeability topseal on the impoundment surface. Leachate drainage from the impoundment would be collected by a series of interceptor trenches located at the Upper Freeport Coal deep mine drainage, in the shallow unconsolidated aquifer and at the Butler Sandstone aquifer discharge zones. Collected wastes would be treated on-site to acceptable discharge limits and then discharged into Stateline Creek. The design of the wastewater treatment facility is not discussed in this paper.

PADER agreed to permit limited leakage of slightly contaminated groundwater from the Butler Sandstone aquifer into the

Table 3
Aquifer Discharge and Impoundment Water Balance

Source	Discharge (gal/min)	Receiving Body
Mahoning Coal Aquifer	2.4	Sludge Impoundment
Sludge Impoundment Pre-Closure	43	Upper Freeport Coal Aquifer and Shallow Unconsolidated Aquifer
Post-Closure	2.4	
Upper Freeport Coal Aquifer	200	Stateline Creek
Butler Sandstone Aquifer	36	Shallow Unconsolidated Aquifer and Stateline Creek
Freeport Sandstone Aquifer	0.7	Stateline Creek
Shallow Unconsolidated Aquifer	20-40	Stateline Creek
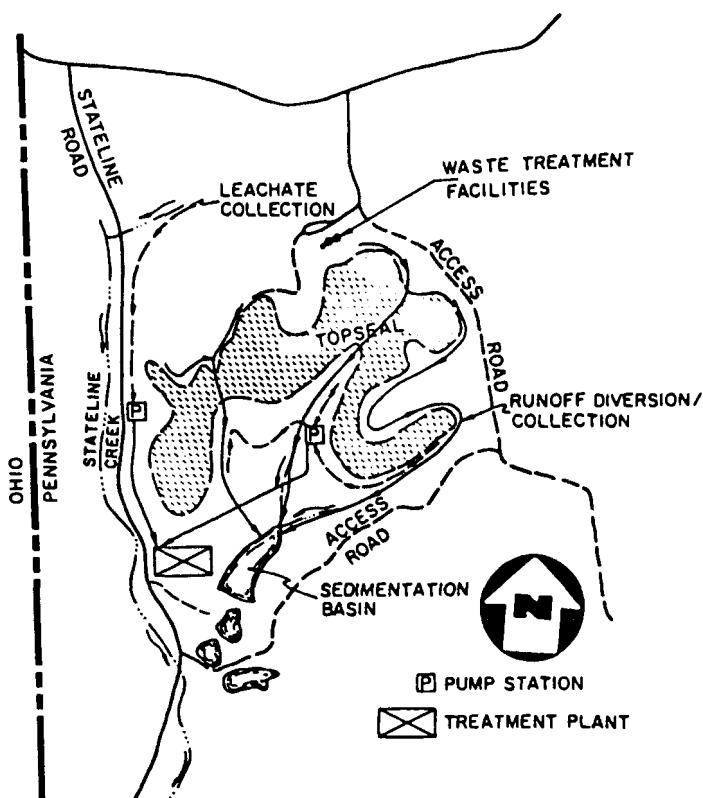
Figure 8
Conceptual Closure Plan

Figure 9
Sludge Pond Topseal

Freeport Sandstone aquifer. The Freeport Aquifer was not significantly degraded, and implementation of remedial measures is expected to improve drainage quality into the aquifer. Post-closure monitoring of the Freeport aquifer was required to assess groundwater quality changes.

Field studies were undertaken to evaluate final cover designs for the impoundment topseal. PADER required a cap with a hydraulic conductivity of less than 1×10^{-7} cm/sec.

A 1 to 2 ft layer of solidified sludge from the process pilot plant already present on the impoundment surface was evaluated as a topseal material. Nine test cells of solidified sludge, 12 ft x 12 ft x 2 ft thick, were constructed on the impoundment surface. Existing placed sludge and various fresh mixes of processed wastes were tested.

The results of the field testing indicated permeabilities of the solidified sludge for all test cells averaged 2×10^{-5} cm/sec ranged from 3.9×10^{-6} to 9.8×10^{-5} cm/sec. Thus, it did not meet the permeability criteria and therefore was not acceptable as a topseal.

An alternate design had to be used (Fig. 8). A 20 mil PVC non-reinforced membrane was selected. It was protected on both sides by a non-woven geotextile fabric.
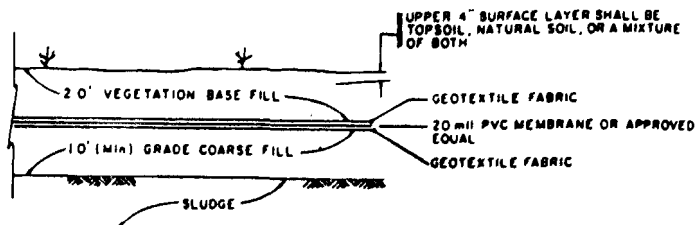
At anticipated cover surcharge thicknesses of 6 to 10 ft, primary (90%) settlements of 5 to 7 ft over 150 to 280 days were estimated. These equate to approximately a 10% settlement.

Since the disposal facility was approximately 23 yr old, most of the sludges were expected to achieve 90% or greater settlement. However, since significant volumes of sludge were disposed in the last 2 to 3 yr of operation, surcharging of the impoundment and monitoring of settlements was proposed as a first stage of closure.

In addition to placement of low permeability topseal and construction of a leachate collection and treatment system, extensive grading, revegetation and surface drainage measures were implemented to minimize rainfall recharge into the local groundwater system and reduce long-term site erosion.

A 5 acre impoundment on the main watercourse below the impoundment was used as the sedimentation basin for closure plan construction. This upper pond is topographically situated and has sufficient capacity to provide the minimum storage requirements for stormwater sedimentation. The pond and two lower ponds along the watercourse were upgraded with stable overflow spillways to protect against excessive erosion.

Stage 1 closure operations commenced in June, 1983. A minimum 2-ft thick cover of local mine spoils was placed over the entire impoundment. Two 10-ft thick surcharge fills were constructed on the two longest impoundment areas in the central pond. Settlement plates were installed on the surcharge fills and surveyed for elevation and horizontal control. Approximately 220,000 yd³ of fill were placed in Stage 1.

Stage 2 construction commenced in May, 1984. Work in this stage includes regrading of the cover fill, placement of the cover topseal, construction of the surface drainage and leachate collection systems and placement of the final cover and vegetation. Approximately 300,000 yd³ of fill will be placed in Stage 2. Stage 2 is presently under construction and is scheduled for completion in October, 1984.

Special considerations were made in construction of the topseal for the 45 acre impoundment. The settlement potential of up to 70 ft of semi-solid sludge had to be accounted for to prevent future slumping of the final cover surface and ponding of rainfall water.

Calculations were made to estimate primary and secondary settlements of the sludges. Sludge properties were taken from laboratory consolidation tests. Basic assumptions included a homogeneous and isotropic medium, instantaneous placement and one-dimensional vertical consolidation.

BENEFICIAL REUSES OF
HAZARDOUS WASTE SITES IN CALIFORNIA

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INTRODUCTION

The California Department of Health Services (DOHS), Toxic Substances Control Division, is the governmental body with primary responsibility for the management of hazardous wastes in California. Laws governing hazardous waste management were initially enacted in California in 1972. Since that time the state has developed and implemented a variety of related programs dealing with facility permitting, regulation of generators and transporters, development of alternative disposal technologies, site mitigation and management of the "State Superfund."

In 1979, the Department of Health Services initiated its "Abandoned Site Project", designed to seek out properties throughout the state where hazardous wastes were once stored, disposed of or otherwise handled. Since its inception, dozens of such sites have been identified, many of which still contain hazardous wastes in piles, lagoons, pits, sumps, storage tanks and/or drums. In many cases, these wastes have leaked from their containers, contaminating adjacent properties and underlying waters. The persons originally responsible for such contamination have frequently died, filed bankruptcy, relocated or sold the parcels to land developers desirous of utilizing the properties for purposes often entirely unrelated to their former uses.

The Department of Health Services is particularly interested in sites slated to undergo redevelopment. While strongly in favor of restoring these former hazardous waste sites for beneficial new uses, DOHS also takes a very cautious approach to redevelopment, carefully considering the potentially severe long range effects such reuse can have if the future intended use is incompatible with wastes still remaining on-site. DOHS therefore works closely with these developers, taking an active role in the characterization of site contamination and in the design of remedial measures which will be fully protective of the health and safety of future site occupants.

Mitigation strategies designed for redeveloped hazardous waste sites must be individually tailored to each situation, taking into consideration a number of vital decision factors. In this paper, the authors present the case histories of three such sites in California, focusing on the cause and nature of the contaminants present, the proposed reuse of each site, selected mitigation strategies and (most importantly) the various decision factors considered in the selection of these mitigation strategies.

BOUCHER LANDFILL

The Mola Development Site, formerly known as the Boucher Landfill, is located in the city of Huntington Beach, California on a low plateau overlooking a wildlife refuge. The 12.4 acre site was originally used as a gravel pit in about 1934. In the 1940s, the site was enlarged and a variety of petroleum refinery-type wastes, including acidified sludges from the production of high octane gasoline, were deposited in the excavation. In the early 1950s, a permit was granted to deposit rotary drilling muds at the site.

It was shortly after this period that adjacent residents began to complain about petroleum or gasoline odors and taste in their well water. In 1963, the site was permitted as a Class II site allowing disposal of building demolition wastes. By 1970, more than 12 public and private wells were closed in the area adjacent to the site due to contamination by materials deposited at the site.

In 1979, the new owner of the property, Mola Development Corp., applied to the city for a conditional use permit and tentative tract map to construct a 224 unit residential development on the site. After deliberating on six separate occasions on the application, the city planning commission decided to pursue a negative declaration for the project on the conditions that additional information be submitted on the nature and extent of contamination and that several mitigation operations be developed for the site.

Extent of Contamination

The subsequent site investigation consisted of 20 boreholes ranging in depth from 15 to 25 ft. Nine of these boreholes were converted to gas/vapor sampling wells. Sixteen existing groundwater wells were located nearby. Five of these were selected for sampling based on their proximity to the site and their completion in the shallow aquifer. The investigation revealed large pools of black, viscous and extremely odorous petroleum wastes at various depths in the fill. At a few locations, this material was found to be oozing to the surface. Due to the porous nature of the fill, surface water had percolated through to leach many constituents of the waste material into surrounding soils and groundwater. A 1963 estimate of the amount of sludge deposited in the fill was 2000 yd³. The revised estimate as a result of these borings was 60,000 yd³ of sludge and contaminated fill. The constituents of primary concern in this material were aromatic hydrocarbons (benzene and toluene), chlorinated hydrocarbons, phenols and a host of organic sulfur compounds (thiophenes). In addition, the waste exhibited very low pH (pH 1-2).

Many of the borings bottomed in sandy lenses indicating some potential for off-site migration. Well sampling showed that some waste constituents, particularly benzene, had migrated almost a mile off-site in the shallow zone.

The landfill gas contained high concentrations of benzene and other aromatic and aliphatic hydrocarbons, including methane. Thiophenes were also found in abundance. The calculated gas emission rate based on the gas well readings was approximately 600 ft³/day.

Mitigation Strategies and Decision-making Factors

Several alternatives were evaluated for effectiveness and feasibility of controlling soil contamination, vapor generation, vapor migration, odors and leachate migration. These alternatives ranged from no action/no project to in situ treatment, encapsulation with gas control and excavation. Despite the findings of the investigation, the developer was still interested in pursuing the project. Because of the uncertainties related to the effectiveness of the in situ treatment and encapsulation alternatives, the City Planning Commission decided to accept the excavation alternative recommended by the regulatory agencies. Concerns about the potential for migration of toxic and odorous compounds into residences built on the fill after treatment or encapsulation, about the further contamination of the aquifer and about the potential for liquefaction in a seismic event were key factors in this decision.

Citizen concerns about the potential health and environmental impacts of the project prompted the Commission to order a full Environmental Impact Report (EIR) for the project which involved removal of an estimated 105,000 yd³ of material at a cost of approximately $2,000,000. The EIR identified the need for a very controlled excavation process, ambient air monitoring, a specified transportation route, special handling at the disposal site and a community evacuation plan. These special measures were required primarily because of the gases and vapors in the waste which would be released upon excavation. Despite these further constraints on the project, the developer was still intent on proceeding. The EIR and the project were finally approved in mid-1981.

The removal activity took place over a period of 2-3 months; this period included several work stoppages as a result of excessive odor complaints from the community. The estimated volume of material excavated exceeded the initial estimates by over 50% and contamination was found to a depth of 30 ft in some portions of the site. The excavation phase was completed in July of 1981.

Building permits were finally issued in June 1983. Currently there are 288 condominium-style residential units on the former hazardous waste site. The units include studios, one bedrooms and two bedrooms with prices ranging from $69,000 to $130,000.

This is one of the first uncontrolled hazardous waste sites in California where redevelopment has occurred and where land use has been upgraded to such an extent. The process involved a careful evaluation of the potential health and environmental risks in allowing residential use of a site formerly used for disposal of hazardous wastes. At the time the decision was made, there was little confidence in the effectiveness of any measure other than excavation in protecting the health of residents of the condominiums. For this type of site, the same decision would probably be made today. Not enough is known about the effectiveness of in situ control measures for migration of gases and leachate to ensure that exposure of residents will not occur in such high-risk situations as redevelopment of contaminated lands for residential purposes.

The incentive for redevelopment of contaminated lands to uses which would provide the highest potential for exposure to contaminants is clearly tied to the high potential for return on investments for residential uses. The desirable locale of a site (one mile from the beach, in this case) is a key factor in determining whether remedial action to the extent that residences can be built is economically feasible. This type of redevelopment is more economically feasible in urban areas such as San Francisco and Los Angeles, where the demand for residential housing is high.

BETHLEHEM STEEL COMPANY

South San Francisco, nicknamed "The Industrial City", was founded in the 1800s as an inexpensive alternative for industries

Figure 1
Condominiums at Mola Development Site, Huntington Beach, CA.
Former Site of Boucher Landfill

seeking the advantages of San Francisco's port location. Numerous businesses, notably the meat packing, paint manufacturing and steel industries, established their operations there at the turn of the century.

The 110-acre site now owned by Homart Development Company was occupied by steel manufacturing companies from 1903 to 1977. Bethlehem Steel operated a full scale steel production facility there complete with open hearth blast furnaces, a milling and annealing operation, welding shops and a galvanizing facility. In 1977, Bethlehem Steel vacated this property, in part due to the heavy costs of complying with environmental regulations.

The site was then purchased by Homart Development Company with the intention of constructing the multi-million dollar "Gateway Center" project, a combination hotel/commercial/office park development. In 1980, this as yet undeveloped property came to the attention of California's Abandoned Site Project as a likely location of hazardous wastes, and characterization efforts were cooperatively initiated by Homart and the Department of Health Services.

Extent of Contamination

Throughout Bethlehem Steel's long history of operation, slag from the steel manufacturing process was disposed of at various locations on the property. These widespread slag deposits contained hazardous concentrations of heavy metals; particularly lead, zinc and chromium. In addition, the open hearth building and surrounding property were heavily contaminated with metals from furnace ash deposition.

PCBs were also detected throughout the site at electrical shops, transformer storage areas and anywhere heavy machinery had been employed. An underground storage tank containing fuel oil for the hearth and mill operations also contained PCBs, but in concentrations less than 50 ppm. An investigation of this area determined that substantial leakage from the tank had occurred, resulting in a subsurface plume of oil approximately 120 by 500 ft. Though the resulting contaminated soils contained only low concentrations of PCBs, some free liquids were still present in underlying fractured bedrock.

Investigation of the underlying groundwater detected only minor concentrations of dissolved metals confined to areas formerly used as acid seepage basins for disposal of pickling liquids. However, these low concentrations were deemed an insignificant hazard to human health or the environment; the high salinity of the

Figure 2
Homart Development Company's "Gateway Center", Site of Former
Bethlehem Steel Plant, So. San Francisco, CA

• The one-foot deep cover must be maintained at all times.
• Excavation will be allowed below the cover provided DOHS is informed in advance and any excavated soils are relocated within property boundaries beneath the one-foot deep cover. Soils which cannot be relocated on-site must undergo laboratory analysis with subsequent disposition subject to DOHS approval.
• Precautions to prevent surface runoff and windblown dust must be undertaken whenever excavation occurs. Appropriate worker safety precautions must also be utilized during excavation.
• Future use of the site is limited to commercial, light industrial, office park and hotel purposes. No residences, schools, day care centers or hospitals may be built.
• The deed restriction transfers to all future tenants and subsequent landowners.

The above mitigation strategy was approved by the regulatory agencies for the following reasons:
• Upon investigation, groundwater contamination was deemed negligible and relatively immobile and the underlying aquifer largely unusable due to high salinity.
• Contaminants remaining on-site were limited to relatively immobile, low toxicity metals.
• All future surface runoff, windblown dust and direct contact with hazardous materials remaining on-site will be precluded via maintenance of the one-foot deep cover. This precaution will further be enhanced through landscaping and through paving of the site for roadways and parking lots.
• Redevelopment of the site will be limited to industrial/commercial uses only, thus reducing the likelihood of any inadvertent or long-term exposure to buried metallic wastes.
• Total removal of metallic wastes was deemed unfeasible from both the standpoints of economics and of limited local landfill disposal capacity due to the depth and extent of contamination on this 110-acre site.

To date, Homart Development Corporation has fully implemented the control strategy required by DOHS. The site has now been fully graded and partially landscaped. A partially occupied 12-story office structure has been erected overlooking San Francisco Bay. Roadways and a connecting ramp to the nearby freeway have been constructed. It is anticipated that this complex of hotels, research/development facilities, office space and commercial/retail buildings will be completed by 1987, providing both an economic boost and a facelift to this former industrial area.

aquifer precluded its use, and migration potential was determined to be severely limited.

Mitigation Strategy and Decision-making Factors

The following mitigation measures were undertaken by Homart Development Company following approval by DOHS:
• All laboratory chemicals from the quality assurance laboratory and other drummed wastes were identified and properly disposed of.
• The underground oil storage tank was pumped, steam-cleaned and the resulting liquids properly disposed of.
• All soils containing hazardous concentrations of PCB were excavated and removed.
• Fractured bedrock containing liquids contaminated with PCB was trenched, dewatered and the resulting effluent separated into oil and water fractions. Remaining oily residues clinging to excavated materials were collected on absorbent material for disposal. Resulting nonhazardous solids were ultimately returned to the site for use as fill.
• Certain areas exhibiting low pHs were neutralized with lime to further deter mobility of metals.
• The site was graded and covered with 1 ft of compacted clean soil.

A restrictive covenant was placed upon the deed to this site and was entered into public record in the county of San Mateo. This document, which is legally enforceable by DOHS and effective into perpetuity, provides the following:

HERCULES POWDER COMPANY

The small company town of Hercules, California grew up around the Hercules Powder Company, an explosives manufacturer which once owned approximately 1300 acres of land in the area. This industrial plant, located in rolling hills 30 miles north of San Francisco, operated as a powder works from 1885 until 1976 and manufactured such chemicals as methanol, ammonia, formaldehyde and nitric acid. These materials were, then transformed into fertilizers and explosives including trinitrotoluene (TNT), nitroglycerine and black powder. For safety purposes, the various explosives production lines were scattered throughout the area and located as much as a mile from the primary chemicals plant.

In 1976, Hercules Powder Company sold its west coast plant to Valley Nitrogen Producers, who continued to manufacture fertilizers there until 1979. At that time, the formerly large holdings of Hercules Powder Company were subdivided and sold in smaller parcels to a variety of land developers and holding companies. These firms, working with the City of Hercules, developed a master plan to transform Hercules from a one-industry town into an integrated series of commercial and light industrial developments, office parks and residential communities.

The California Abandoned Site Project became aware of this former explosives/fertilizer operation in 1980. At that time, the City of Hercules approached DOHS with its area-wide development proposal and requested aid to resolve any hazardous waste issues. Since then, DOHS has worked closely with many recent

purchasers of these parcels to characterize and mitigate contaminants present on their sites. Indeed, consideration of the potential presence of hazardous wastes on these properties has become a vital component of the Environmental Impact Report process for the area.

Extent of Contamination

Each of the several parcels sampled has elevated concentrations of heavy metals, notably lead and zinc. These metals appear to be associated with spilled catalyst materials or empty decaying drums strewn about the premises. Several areas also contain persistent, toxic, organic explosives, such as trinitrotoluene (TNT), dinitrotoluene (DNT) and dinitrobenzene (DNB). One area, used primarily for the discharge of contaminated wastewaters, contained one lined and two unlined discharge ponds containing metallic sludges and/or explosives. Another parcel (the one most heavily contaminated with explosives) contained the remains of the old TNT production facility along with two large, submerged urea tanks. A third parcel housed the black powder line. Old bunkers contaminated with metals and explosives were found at several sites, and many aboveground storage tanks (some still containing liquid chemicals or residues) were located at the old primary chemicals plant.

Groundwater monitoring has detected no significant contamination of the underlying aquifer which is considered too saline to be used for most beneficial purposes. Residents and businesses in the area draw their water only from the municipal water supply.

Mitigation Strategies

So far, formal mitigation plans have been developed and approved for five of the seven sites currently characterized. These plans are based on the nature of the contamination and the future intended land use.

Three of the sites with approved mitigation plans are to be developed for residential purposes including condominiums, single-family dwellings, schools, parks and playgrounds. They were required to undertake stringent cleanup measures including total removal of contaminants to DOHS-determined nonhazardous or background concentrations.

The other two sites with approved mitigation plans are to be used for commercial and light industrial purposes. The owners of these sites were offered the options of: (1) totally removing site contaminants to nonhazardous levels, or (2) removing heavily contaminated soils to some intermediate cleanup level established by DOHS, encapsulating remaining hazardous wastes on site and accepting a deed restriction on those areas still containing hazardous wastes. One site owner opted to completely remove wastes, finding this alternative preferable to the perpetual restrictions imposed by a deed covenant. The other owner has, for economic reasons, tentatively chosen to relocate all remaining wastes to a deep gulch area on-site where encapsulation will occur. This area will be subject to a deed restriction similar to that currently in effect for the Homart Development site, while clean areas of the property will be available for unrestricted future use.

Factors considered in choosing these mitigation strategies include the following:
- Groundwater contamination was nonexistent or negligible at all sites. Underlying water was also of limited usefulness due to high salinity, and all residences and businesses in the area are to be connected to municipal water supplies.
- Stringent cleanup measures resulting in unrestricted future property uses were deemed essential at residential, school and playground properties for several reasons:
- Occupants of residential-type properties, and particularly children, would have a higher likelihood of contacting hazardous waste residues left in place on these properties than would workers employed on commercial/industrial sites. Mechanisms for such exposure would include playing of games such as baseball on dusty, undeveloped lots or un-

Figure 3
Citation Homes, One of Many Developments Under Construction at the Site of the Old Hercules Powder Company, Hercules, CA.

paved schoolyards, ingestion of soils by small children playing in unlandscaped backyards, ordinary gardening and landscaping (followed by consumption of foods without prior washing of hands), ingestion of foods grown in contaminated gardens and possible installation of domestic wells by persons lacking knowledge of groundwater use criteria.
- Residential occupants may represent a more vulnerable population than workers at a commercial site, as small children, the elderly and invalids are more likely to be represented in the former group. In addition, workers are protected to some extent by occupational safety organizations, whereas homeowners are not.
- Residential occupants exposed to hazardous wastes at their homes are more likely to experience a longer exposure period than workers who spend a finite amount of time at their workplaces.
- Contaminants present included not only metals but relatively persistent organic explosives. While not an explosive hazard under site conditions, these compounds do exhibit moderate to high toxicity via several routes of exposure. In addition, DNT is a suspected carcinogen. Considering these toxicities and the fact that these materials are not normally encountered in the natural environment, extra levels of precaution were deemed prudent in residential scenarios.
- It was considered unlikely that DOHS could effectively police land use restrictions imposed on private residences due to the large number of properties affected.
- Lowered property values may result at residences located on hazardous waste property subject to deed restrictions.

For all of the above reasons, complete removal of hazardous wastes from residential properties was considered to be the miti-

gation alternative most protective of public health and safety as viewed by DOHS and the most desirable as viewed by the developers involved.

•Land use restrictions were offered as an alternative mitigation to those developers intending to use their properties for commercial or industrial purposes for several reasons:

•The control measures included in such restrictions would effectively prevent all surface runoff, windblown dust and direct contact with underlying wastes.

•Any exposure which may inadvertently occur via excavation activity would be of limited duration due to the intended use of the property. For the same reason, excavation activities would also be subject to control by occupational safety organizations.

•All very hazardous contaminants, as determined by DOHS, would be removed from the property prior to encapsulation and imposition of the deed restriction.

•Widespread contamination could render complete removal of wastes unfeasible and undesirable, both economically and from the perspective of available landfill capacity.

Today, cleanup and control of the hazardous wastes from the old Hercules Powder Plant is well underway. More than 12,000 yd³ of contaminated soils have been excavated, and the carefully planned development of the City of Hercules has been launched. Two model home developments are now open. When complete, this region-wide project will preserve elements of this town's colorful past while updating the community with new housing facilities and increased employment opportunities.

CONCLUSIONS

Redevelopment of former hazardous waste sites can be successfully accomplished when certain precautions are taken to fully protect the health and safety of all future site occupants.

Factors to be considered by regulatory agencies in designing mitigation strategies for such sites must include the nature of the contaminants present (i.e., their degrees of hazard via various routes of exposure, mobilities in soil systems, persistence, degradation potential, volatility, etc.), the actual and potential extent of contamination in soils, air, surface and groundwaters, beneficial. uses of these potentially effected water resources, the feasibility and reliability of all available mitigation strategies and the intended future land use.

Land developers must consider an additional set of decision factors when confronted with agency-approved mitigation alternatives. Among these factors are the cost of each mitigation strategy (in time and money), potential resale value of redeveloped sites if those sites still contain waste residues, the need for possible long-term involvement with a site via pollutant monitoring or deed restrictions, overall return on investment and potential public relations issues.

By working together cooperatively on all phases of site investigation and remedial design, land owners, city development authorities and environmental regulatory agencies can ensure that former hazardous waste sites may be redeveloped for beneficial new purposes while serving the community in productive capacities which are also fully protective of public health and safety.

PUBLIC INFORMATION NEEDS IN THE SITING AND CLEANUP OF HAZARDOUS WASTE SITES

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THE PUBLIC'S NEED TO KNOW

Some basic tenets of public participation in hazardous waste activities have become clear from the experience of the past few years:
- The public will continue to be interested and involved in issues surrounding the siting, expansion and cleanup of hazardous waste sites.
- The public has the right to know and participate in decisions affecting health and welfare. The public recognizes this right.
- Public involvement in the decision-making process is absolutely essential in finding and implementing acceptable hazardous waste solutions.

Government, industry and the public have been struggling to create effective public participation processes that address these basic facts. The Superfund program strongly emphasizes two-way communication between communities and government throughout all Superfund activities and has continuously refined its policies and procedures in response to what has been learned over the past four years. RCRA's community relations program is also being expanded. Industry has learned—sometimes painfully—that underestimating the public's need to know is done at its own peril.

"Underestimating" and "peril" are key words. The public has become increasingly sophisticated about environmental and health-related issues. Grass-roots politics, the environmental movement and consumer information programs have provided skills and insights to people who are demanding accountability from those who affect their lives. Unfortunately, the generation and disposal of hazardous waste have not always been entirely accountable, intensifying the public's apprehension and its resolve. People are afraid. Uncontrolled hazardous waste is dangerous, and the danger can be long-lived. People are educating themselves about how they and their children are being affected and how they, in turn, can have an effect. This combination of intense concern, increased awareness and political know-how has given the public a powerful voice in the decision-making process.

WHAT IS AN INFORMED PUBLIC?

There is general agreement that any future siting, operation and cleanup of hazardous waste facilities will be a joint—and, ideally, cooperative—effort among government, industry and the public. Processes for public involvement continue to evolve. The goal of these processes is to foster responsible, effective participants—in short, an informed public.

The question then arises of the meaning of "informed." What do people need to know to weigh the alternatives and make choices? What do they want to know when their lives are directly touched by some aspect of hazardous waste? What kind of public education programs and materials can provide this information?

Past experience has shown that a number of central issues are commonly raised by the public, and that adequate information has not always been provided to address them. These issues and information needs are discussed below. First, an important point needs to be made.

There are two dimensions to information: (1) facts and (2) understanding. For issues as complex as those surrounding hazardous waste, facts alone are seldom adequate to meet the public's need to be informed. The subject is fraught with complexities, limitations and unknowns that require explanation.

The following example demonstrates the possible gulf between facts and understanding. A groundwater monitoring program is established, and residents are told their wells are being tested for possible contamination. After a while, they are mailed results that are, for all practical purposes, in an indecipherable code of initials and numbers. They are perhaps told that further testing may be performed. For now, however, there is no immediate cause for concern, since no volatile organic chemicals exceed the state action level of $5 \mu g/l$, based upon a 10^{-6} cancer risk level.

These are the basic facts, but these residents can hardly be called well informed. More likely, most of them are unable to derive any true understanding from this information. As a result, they cannot determine what the data mean to them or use the information to make meaningful decisions. They may decide not to worry or to drink bottled water as a precaution. Or they may decide to organize their neighbors to demand immediate cleanup action.

The process of risk assessment offers another illustration.[*] Estimating human health risks from exposure to certain levels of contaminants contains a great deal of uncertainty. The public would like to believe there are experts who can determine these risks with a large degree of accuracy. Estimates of risk, however, are based on reasonable assumptions subject to change at any time. Numbers and values are assigned, and regulatory decisions are made, but they are not based on definitive scientific facts. In addition, risks can never be reduced to zero. Choices sometimes have to be made —between jobs and health impacts, for instance, or between economic development and increases in pollution.

The public needs to recognize the tradeoffs and limitations. But the public should also understand the value of attempting to quantify risks and the reasonableness of the process. Half explanations, apparent contradictions and obscure processes will result in a confused, suspicious public. Only fully informed citizens will be able to participate in complex decision-making.

CHECKS AND BALANCES

Distinguishing between fact and understanding has an additional benefit: it acts as a system of checks and balances for those responsible for hazardous waste activities. Information that is meant to convince the community that disposal and cleanup can be satisfactorily accomplished must, in fact, be convincing. To describe a process, it must first be examined; to explain a decision, it must be reasoned. The act of writing—or the thought of speaking at a public meeting to people who are demanding to know—can serve as an impetus toward clear thought and reexamination.

The goal of genuine understanding also makes it easier to provide information that is appropriate. The basic question that should be asked is: What does the public really need to know in these circumstances? Answering this question requires listing to the community carefully, hearing not only the words, but also the fears, frustrations and anger that may be behind them. It requires measuring information already given to the community against community perceptions of this information. It means replacing one-way assumptions with two-way communication. In the end, it helps prevent the costly error of offering information that is off-target, inadequate or insulting.

ISSUES AND INFORMATION NEEDS

With these thoughts in mind, some major issues and information needs are presented.

Health Effects and Risk Assessment

Some of the most fundamental issues that arise concern the possible health effects associated with hazardous wastes. They are also some of the most complicated. As discussed previously, so much is still unknown about the risks associated with many contaminants. Yet, decisions must be made, and their basis must be explained to the public. Health issues are further complicated by the emotion that often surrounds them. People's fears are very real, even when they do not seem to be based on "fact."

This was clearly demonstrated at a Superfund site in California. Residents near the site were extremely concerned about what they perceived to be an abnormally high incidence of cancer and miscarriages in their community. A number of people had also been complaining of headaches, nausea and vision problems for a number of years. A local health clinic screened 75 residents, and the county health department examined the findings. The county reported that "the observed morbidity of residents was not out of the ordinary and that no observed occurrences were statistically significant." Residents simply did not believe this conclusion. They organized to press for further health screening, which is now being conducted by the state.

Discussions with community members clearly showed why they would not accept the initial conclusion. They felt the information they had received was unclear and inconsistent. They did not receive adequate or timely responses to their questions, and the language of scientific detachment that was used to give them the results was totally inappropriate to their needs. The current health survey will inevitably have the same credibility gap unless it profits from these lessons.

It is important that regulatory agencies and industries work closely with health professionals to develop materials about health effects and risk assessment. The answers must be not only technically sound and thorough, but must also be understandable to the lay public. Because these issues are so volatile, the public may still not believe certain findings. Studies may still be challenged if they show no connection between perceived health problems and a site that looks and smells terrible, but the chances of public acceptance can certainly be increased by improved communication.

*The discussion about risk assessment is based upon: Rifkin, E., "Assessing Risks for the Biscayne Aquifer System." *Remedies: An Update of Hazardous Waste Issues*. Biscayne Aquifer Project, USEPA Region IV, Atlanta, GA., July 1984.

Costs and Benefits

Another major concern of community members is the impact of new facilities or uncontrolled hazardous waste sites on their property. They fear that existing or potential contamination may lower property values, make it difficult to sell or put restrictions on development. While these costs are probably of greatest concern, other costs may also be associated with hazardous waste sites: bottled water must be used if wells become contaminated; medical costs are incurred if health effects are experienced. At one Superfund site in Colorado, the fire district required several businesses to install methane detection systems because the businesses bordered a landfill from which methane gas was migrating.

People question why they must pay for the consequences of someone else's actions. In some cases, these costs can have a significant impact on their lives. Again, the answers may not always be wholly satisfactory. But the questions warrant serious attention and thorough explanation.

A new hazardous waste disposal facility can also offer economic benefits such as jobs and training programs, tax revenues and local purchases of supplies and equipment. These positive impacts should also be understood by a community involved in siting issues. They can then be weighed against the possible negative impacts, enabling the making of reasonable choices.

Groundwater

Groundwater is a complex technical subject. It is also at the heart of many hazardous waste incidents. In a USEPA study of 881 sites evaluated through the hazardous ranking system, 60% of the sites involved releases of contaminants into the groundwater, with a potentially exposed population of 8.2 million people. Some years ago, many people probably did not even know that groundwater was their drinking water source; today, the increasing threat to this source has resulted in a much greater awareness. However, this awareness does not always extend to an understanding thorough enough to address the issues.

Residents may not understand how one well can be highly contaminated while adjacent wells are clean. Terms such as "plume" and "aquifer" are still foreign to many people. And the public probably does not yet realize its contribution to groundwater contamination through small releases of hazardous materials. Educating the public about this subject can help people understand groundwater problems. It can also help prevent them.

Contaminant Standards

Contaminant standards—or the lack thereof—are often not well understood by the public. Terms such as "maximum contaminant level," "primary drinking water regulations" or "state action levels" are confusing. People may not understand how allowable contaminant levels or cleanup criteria are determined, particularly in cases where no enforceable standards have been established. These issues are closely tied to risk assessment and suffer some of the same complications. As with risk assessment, however, the rationale and limitations need to be explained as completely as possible.

Safety and Reliability

A number of issues are incorporated within this general heading. Common to them all is the public's desire to know what risks and assurances are associated with siting or remedial actions.

• *Technical processes:* How does a proposed technical process work? What can go wrong; what are the chances of this happening? Are there any by-products that could have negative impacts?

The public is participating in more and more sophisticated evaluations: air stripping versus carbon adsorption; off-site disposal versus on-site containment; the reliability of proposed new facilities. Appropriate levels of technical background must be provided to assist in these evaluations.

• *Regulatory Safeguards:* What are the regulations for site construction, operation and closure? What safety measures, emergency procedures and contingency plans will be provided?

It may not always be adequate to offer assurances that local, state and Federal standards are in place and must be met. The public may want to know exactly what the standards are, on what they are based and how they will be fulfilled.

• *Oversight and Enforcement:* Who is responsible for ensuring that regulations are being met and that enforcement will be carried out?

Past performance is a crucial element here. The credibility of the responsible authority must be established before public acceptance will occur.

Programs and Policies

Questions often arise about hazardous waste programs and policies. Funding priorities and schedules for Superfund remedial actions are generally not well understood. The definition and legal liability of responsible parties also need to be clarified in many cases. Low-income communities sometimes perceive that sites in their neighborhood are given lower priority than sites in high-income areas. Residents buying bottled water or suffering decreased property values wonder why they are carrying the burden instead of the waste generator. These concerns must be addressed and can sometimes be explained only within the broad context of regulatory programs and policies. Good explanations may not always be forthcoming. If so, this is also a legitimate topic of discussion. Limitations and omissions must be examined if the public is to be truly involved in guiding public policy.

PUBLIC INFORMATION MATERIALS

In developing public information materials, some basic guidelines should be kept in mind:

• Materials should contain the information that is needed. This means the audience must be clearly defined and its concerns must be identified. While this advice may seem obvious, past experience shows it has not always been followed.

• Information should match the audience's level of concern. Materials should be neither condescending nor inappropriately elaborate.

• Information should be well organized and clearly presented.

• Information should be timely and accessible. The public should know when and where it is available.

• Technical, legal and other specialized terms should be avoided if they are not necessary and well explained if they are used.

• Slick, flashy materials are not appropriate. At best, they are unnecessary; at worst, they can be perceived as a public relations ploy and a waste of money.

• Some thought should be given to what vehicles best convey the information. Fact sheets can be used to explain the various aspects of a project and to provide periodic updates. Newsletters may be appropriate for providing ongoing information to a large audience. Where complex issues are involved and more thorough public education is desired, issue papers, technical summaries or question and answer sheets should be considered. In some cases, public needs can best be addressed at public meetings that allow two-way communication. Finally, graphic materials can be an effective supplement to written or oral presentations. A diagram that explains a technical process can greatly enhance a technical summary. A slide presentation at a community meeting can give people an accurate mental image of a proposed project. Like written materials, graphic materials should be clear, well presented and appropriate to the audience.

CONCLUSIONS

The public will continue to be involved in the siting, expansion and cleanup of hazardous waste facilities. Past experience has identified a number of major issues that commonly arise and must be addressed. Government and industry should provide information to help the public understand the complexities surrounding hazardous waste activities. Only a truly informed citizenry will be able to participate in responsible decision-making.

COMMUNITY RELATIONS ACTIVITIES FOR ENFORCEMENT-LEAD SUPERFUND SITES

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INTRODUCTION

A potential obstacle to success in the Superfund program can arise when there are differences between the results of government response and enforcement efforts and expectations of citizens concerned about sites. Although a remedy may meet all the legal and technical criteria established for the Superfund program, it may still be perceived as inadequate by citizens living and working near the site.

The objective of the Superfund community relations program is to minimize or avoid this obstacle to success by creating a constructive exchange of information between citizens and government response and enforcement staff. Through this exchange, citizens can learn about the capabilities and limitations of the Superfund program, and program staff can consider and incorporate, where possible, the concerns of citizens into their remedial and enforcement efforts.

In this paper, the authors explore the role of citizen participation during the Superfund enforcement process and describe several mechanisms for including citizens in enforcement deliberations. Except where noted, the views expressed are the authors' and do not represent USEPA policies.

The USEPA has established requirements and procedures for ensuring that the public receives information about site problems and cleanup efforts and has opportunities to comment on proposed response actions. The USEPA must develop a site-specific community relations plan for every Superfund-financed response action. These plans must be based upon personal, on-site discussions with concerned residents, citizen group representatives and local government officials in the site area.*

The challenge to the community relations program is greater, however, when the USEPA is conducting enforcement actions to secure cleanups by potentially responsible parties. Confidentiality is often essential to successful enforcement efforts during or before negotiations or litigation with parties potentially responsible for the release of a hazardous substance. Confidentiality is important to ensure that civil cases are not pre-tried by the public and the media and to encourage candid and open exchanges of information between potentially responsible parties and state and federal government enforcement personnel. Because the government's negotiating position is greatly influenced by the strength of its case against responsible parties, inappropriate disclosures of informa-

tion may undermine efforts to secure proper cleanup at a site. In practice, these concerns often mean that the USEPA conducts enforcement-lead responses largely or wholly removed from public view.

Residents in the vicinity of a Superfund site, however, have a legitimate interest in the outcome of a Superfund response action regardless of whether that response is a Fund-financed government cleanup or an enforcement action. It is the citizens—not the government or the potentially responsible parties—who must continue to live and work near the site long after the completion of response actions. When citizens perceive their mental and physical health to be at stake, they can be expected to demand that their interests be defended. Therefore, when enforcement efforts are conducted in confidentiality between potentially responsible parties and the government, citizens are naturally inclined to be skeptical of cleanup decisions because they perceive themselves to be excluded.

Can citizens be included in the Superfund enforcement process in an active, meaningful way without jeopardizing the legal rights of potentially responsible parties and the government's chances for settlement? In most cases, they can. Moreover, both government and private parties involved in enforcement actions have an obligation to encourage public participation in response decisions affecting the community. Community relations activities may be performed at six points during Superfund enforcement actions:

- Prior to the remedial investigation and feasibility study
- During and upon completion of the remedial investigation and feasibility study
- During and upon completion of negotiations with potentially responsible parties
- During and upon completion of litigation
- During responsible party cleanup
- During removal actions

The USEPA's policies are not binding on states unless the USEPA is funding state-lead activities. So far, the USEPA has not funded any state-lead enforcement activities due to constraints imposed by the Superfund law. However, the USEPA has recently interpreted the law to allow funding assistance for remedial investigations and feasibility studies at state enforcement-lead NPL sites, and will begin to provide such assistance in fiscal year 1985. USEPA policies regarding community relations during the RI/FS will apply in these instances. If the law is amended to allow a broader range of enforcement funding support, then other provisions of USEPA community relations policy can be made applicable to state enforcement actions.

*For more details on the requirements and techniques of the Superfund Community Relations program, see "Community Relations in Superfund: A Handbook, Interim Version", September, 1983, USEPA.

COMMUNITY RELATIONS PRIOR TO THE RI/FS

Remedial enforcement actions can benefit greatly from an understanding of the concerns of the local community near a site. USEPA policy requires the development of a community relations plan based upon on-site discussions for all Superfund enforcement actions. On-site discussions provide an opportunity for USEPA staff to:

- Learn about the history of the site from the unique perspective of citizens living and working in the vicinity
- Gauge effectively the level and nature of citizen concerns about the site and their expectations for cleanup
- Determine the techniques for providing information to the public most preferred by citizens and the issues about which citizens wish to have input
- Identify any other issues or information about which the USEPA may be unaware

These discussions may be particularly helpful to enforcement efforts. Residents familiar with the history of the site may help strengthen the government's case by providing information about the past or present actions of responsible parties.

A USEPA policy issued in January, 1984 should enhance the value of on-site discussions in yielding information about potentially responsible parties. Under this policy, USEPA staff may release the names of potentially responsible parties to the public, either in response to a Freedom of Information Act request or on the Agency's initiative. USEPA staff must inform citizens that the parties' liabilities are not proven, but that those parties have received or may receive notice letters informing them of their potential liabilities. Releasing these names may prompt citizens to provide important information about the parties that they might otherwise have considered unimportant to Agency enforcement efforts.

There is another, perhaps more important, reason for conducting on-site discussions with citizens early in an enforcement-lead response. Government negotiators should have a clear understanding of the expectations of local residents for cleanup at a site before entering negotiations with potentially responsible parties. Those expectations should then be considered when the government develops its negotiating strategy. Although negotiated cleanups may not always meet citizens' expectations, public understanding of such settlements can be better achieved if government negotiators have demonstrated a willingness to consider public concerns in preparing for enforcement action.

By conducting on-site discussions early in the response, the USEPA can develop a community relations plan tailored specifically to the information needs and concerns of local citizens. For enforcement-lead sites, the plan should be developed in consultation with legal and technical enforcement staff to ensure that the schedule of community relations activities is consistent with the schedule for enforcement actions. The plan should also contain provisions for a routine review process so that the appropriate enforcement officials can approve all information to be released during the response.

COMMUNITY RELATIONS DURING AND UPON COMPLETION OF THE RI/FS

Once the remedial investigation begins, community relations activities should proceed in accordance with the community relations plan. It is entirely appropriate, in most instances, to hold public meetings, small group meetings, workshops, to conduct other informational activities to respond to public inquiries and to discuss site conditions, findings of studies and alternative remedial actions under consideration. To avoid undermining possible future enforcement efforts, however, the USEPA must refrain from discussing preferences for a particular remedy, the Agency's enforcement strategy or the attitudes or positions of potentially responsible parties.

If the USEPA is in active litigation during the remedial investigation and development of the feasibility study, community relations activities are subject to the approval of the Department of

Justice and the courts. In addition, if USEPA officials believe litigation will occur later in the response, legal enforcement staff may decide to place some limitations on the information released during the remedial investigation and feasibility study. The government may discuss site conditions and the status of response efforts, but interpretations of technical data may need to be avoided in order not to put Agency or state officials on the record in a way that may jeopardize future litigation strategies. Whenever such confidentiality is necessary, however, the USEPA should explain fully why it is necessary.

When the feasibility study is complete, it should be released for public comment, unless litigation concerns dictate otherwise, so that citizens have an opportunity to examine and critique the study's evaluation of alternative response measures.

COMMUNITY RELATIONS DURING AND UPON COMPLETION OF NEGOTIATIONS

Negotiations are one of the most sensitive aspects of an enforcement-lead response and, therefore, the least amenable to public participation. This should not mean, however, that contacts with the community must cease while the USEPA negotiates with responsible parties. To most citizens, the negotiating process is a mysterious "black box" from which settlements emerge that may or may not meet their expectations. It is perfectly reasonable to explain to citizens in general terms how negotiations are conducted and why it is important to ensure a measure of confidentiality. Citizens should be fully informed of the generic issues that are discussed during negotiations in addition to the technical aspects of the remedy, such as releases from liability for work completed and penalties for noncompliance. Any release of information during negotiations must be approved by the appropriate enforcement officials, however, in accordance with the review procedure set out in the community relations plan.

The USEPA's experience shows that citizens respond favorably when the mystery surrounding negotiations is removed and the USEPA staff are straightforward about what can and cannot be revealed. At one Superfund site, for example, USEPA enforcement and community relations staff met regularly with citizens throughout the course of negotiations. When citizens asked questions which were too sensitive to answer, the USEPA staff honestly stated their inability to answer. Ultimately, the citizens came to trust the USEPA's responses and understood that certain issues could not be discussed publicly. At the same time, enough questions could be answered to assure the citizens that their interests were safeguarded. In addition, the USEPA staff convinced the potentially responsible party to meet with citizens to hear their concerns directly. The company also attended other meetings to present its study proposal and to accept comments, many of which were incorporated into the final agreement.

A public comment period on the final agreement should always be conducted. Administrative consent orders will contain a stipulation that public comments may result in modifications to the order. When the comment period is over, the USEPA should prepare a responsiveness summary to be sent to the appropriate Regional official, who will then recommend either that the order be signed without change or that negotiations be reopened to consider the issues raised by citizens. In any case, the order does not go into effect until it is either signed unchanged or modified and approved by USEPA negotiators and responsible parties. Those provisions unaffected by potential changes may, however, be implemented without delay.

COMMUNITY RELATIONS DURING AND UPON COMPLETION OF LITIGATION

Litigation may or may not be initiated at a given site and, if initiated, may occur at any point during an enforcement-lead response. Community relations activities conducted after a complaint has been filed in a federal district court must be approved in advance by the Department of Justice of the Assistant U.S. Attorney. If a case is being tried in court, the judge will often have final

authority to decide whether community relations activities may be conducted. Thus, it is inadvisable to provide contingency plans for community relations activities during litigation in the initial community relations plan developed prior to the remedial investigation and the initiation of an enforcement action. A better approach is to revise the community relations plan once the USEPA refers a case to the Department of Justice.

If litigation results in a consent decree for site cleanup, the Department of Justice conducts a public comment period on the terms of the decree, consistent with Department procedures, and prepares what amounts to a responsiveness summary for the court. The Department may seek to amend the decree based upon the comments received, or the decree may be signed by the court and take effect without change.

COMMUNITY RELATIONS DURING A RESPONSIBLE PARTY CLEANUP

Even when enforcement activities are successful and result in a cleanup managed by responsible parties, the USEPA remains responsible in the eyes of the public for the technical results achieved. Therefore, the USEPA should ensure that adequate community relations activities are conducted throughout the design and construction of the remedy. In some cases, the responsible party may participate actively in community relations activities, but the USEPA should provide careful oversight in such instances. The appropriate roles of responsible parties in conducting community relations activities should be determined on a case-by-case basis, taking into consideration past experiences with the responsible parties. For example, responsible parties who enjoy community support may be capable of effectively conducting community relations activities.

COMMUNITY RELATIONS DURING REMOVAL ACTIONS

During removal actions, enforcement activities and community relations activities are usually significantly reduced in scope and duration. The USEPA generally does not conduct negotiations or initiate litigation for removals, unless there is sufficient time before site action must begin. The USEPA may, however, issue a unilateral administrative order to compel responsible parties to take discrete actions to abate an immediate threat, or arrive at an agreement with the responsible party to undertake the work. This agreement would be embodied in an administrative consent order.

Once issued, a unilateral administrative order or a consent order becomes a public document and should be made available for public inspection. The USEPA community relations staff should be prepared to discuss the terms of the order and respond to any questions or concerns raised by citizens. If the responsible party fails to comply with the order, however, the appropriate enforcement officials should approve all releases of information to the public in the event civil action may occur.

If an administrative consent order is issued for a longer term removal action, the USEPA should conduct an abbreviated, two-week public comment period consistent with USEPA policy on initial remedial measures.

CONCLUSIONS

In conclusion, the USEPA has an obligation to inform the public and seek citizen input as much as possible during enforcement activities at a site. Citizen awareness of hazardous waste problems is at an all-time high, and citizens are continuing to demand more involvement in decision-making.

Community relations is particularly important for Superfund enforcement actions because the confidentiality that in many instances necessarily surrounds such actions can reinforce, rather than diminish, citizen skepticism. Retreating from contacts with citizens is the worst response because it erodes credibility even further. Instead, community relations during enforcement actions should be approached with the knowledge that a successful enforcement action demands a clear understanding of citizen concerns and expectations and that citizen input can effectively complement enforcement efforts.

In some instances, certain information may be judged too sensitive to be released to the public. Nevertheless, only by listening to citizen concerns and responding honestly to them—even if responding honestly means admitting that certain information is confidential—can the USEPA earn and maintain the public trust.

MANAGING CONFLICT IN CONTROVERSIAL SITING ISSUES: THE KEYSTONE PROCESS

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INTRODUCTION

Public opposition to new waste management facilities continues to be the most important factor in unsuccessful siting attempts. In recognition of the powerful influence of local residents and the general public in permitting procedures for these facilities, many states have devised procedures and formal structures to allow for citizen input. The State of Texas has opted to use the Keystone Siting Process. In this paper, the authors describe public participation processes tried in other states and the Keystone Siting Process.

PUBLIC PARTICIPATION IN OTHER STATES

The approaches taken by other states to the public participation problem fall into four major categories:
• Private negotiation with a local committee
• State ownership of disposal site
• Approval of site by state siting board
• Approval of site by local committee or council

Massachusetts

Massachusetts has chosen the first course of action. The Massachusetts Hazardous Facility Siting Act went into effect in 1980. It represented one of the first efforts to institutionalize the concepts of negotiation and compensation into the hazardous waste siting process. The Act calls for negotiation between the community where a site is to be located and the applicant in an effort to determine what compensation and/or mitigation might be necessary to make the development acceptable to the community.

Specifically, the Act created a 21 member siting council made up of state officials, environmental and public interest representatives, scientists, other interest groups and the general public. The council oversees the functioning of the siting process which is initiated by a developer when a site is proposed. The board makes a preliminary decision on the application to eliminate frivolous proposals and then oversees the creation of a local assessment committee, a local group which will participate in negotiations with the developer. The local assessment committee has the power and the duty to represent the host community in negotiations with the developer, to negotiate specific mitigation measures and obtain compensation for remaining adverse effects, to enter into a binding siting agreement and to appoint two local residents to serve as voting members of the siting council.

To date, four applicants have filed notices of intent with the siting council. None of these applicants has successfully moved through the process and, in fact, three of them have withdrawn their applications. The fourth application is still in process. None of the four applications has reached the negotiation stage in the

process. Those who have been observing the process have speculated on why this is the case, and it appears to be the result of a number of factors, including:
• The process calls for a preliminary screening of a notice of intent by the siting council to determine whether a proposal should enter the process. Fifteen days were provided for the council to make its determination. Communities, however, have pressured the board to make substantive determinations on the merits of the project in this period. This pressure has held up the progress of the applications and led to solid positions being taken by the public long before sufficient information is available.
• A second problem has been the fact that it is very difficult for the state (or any portion of the state bureaucracy) to remain truly neutral in the negotiation process. The siting board has to make substantive and procedures decisions such as determining which communities should receive technical assistance grants available under the Act. Not surprisingly, the board has come under heavy criticism for the decisions it has made.

Overall, the Massachusetts siting approach has not been as successful as those who conceived it had wished. The realities of siting facilities present a great challenge even to those processes designed to be responsive to the needs of the various parties concerned with siting decisions.

Wisconsin

Wisconsin's plan is another variation of the private negotiation with a local committee option. In May, 1982, a major revision to state law in Wisconsin established a mechanism for negotiations between the prospective operator of a site and a local committee representing affected municipalities. It also created a Waste Facility Siting Board to arbitrate in case of impasse.

The negotiation/arbitration process was designed by an *ad hoc* legislative committee representing the state senate and assembly and industrial, environmental, state agency, regional planning and local government interests. The committee wanted to involve local parties at an early stage in site development, but with a minimum of delay to the siting process. So, under the law, negotiations are set in motion ahead of regulatory procedures conducted by the Department of Natural Resources and may continue, if necessary, as an independent but parallel process.

Governmental entities that are eligible to appoint members to the local committee are:
• Any town, village or city in which all or part of the facility will be located (four members)
• Any county in which all or part of the facility will be located (two members)

•Any town, village, city or county whose boundary is within 1,200 ft of that part of the site where waste will actually be disposed, stored or treated (one member)

The triggering mechanism for negotiations is passage of a siting resolution by any affected municipality. The siting resolution is sent to the Waste Facility Siting Board which then notifies the other affected municipalities that they must pass a siting resolution within two weeks to be eligible to participate in the local committee.

Once all the siting resolutions have been passed and local committee members have been appointed, negotiations can begin. To become binding, all items agreed to by the local committee and the applicant must be approved by the governing bodies of the communities in which all or part of the facility will be located. Eligible items on which agreement cannot be reached may be included in an arbitration proposal to be decided by the Waste Facility Siting Board.

Any item may be the subject of bargaining except the need for the site or any proposal that would weaken environmental protection measures. The topics that may be arbitrated are fewer and are listed in the statute. If it believes further progress toward settlement is possible, the siting board is empowered to order continued siting negotiations.

The Waste Facility Siting Board is a seven-member body composed of representatives from four state agencies (Transportation; Development; Industry, Labor and Human Relations; and Agriculture, Trade and Consumer Protection) and three local elected officials (two town and one county) appointed by the Governor.

Once the board accepts a case for arbitration, it must choose between two final offers presented by the parties. The final offers may include only items that have been offered in negotiation and are defined as arbitrable under the law. The board must select one of the final offers in total and may not select items from each. If the board fails to decide by at least a five to two majority, the arbitration decision will be made by the Governor.

The board had its first meeting in late August, 1982. It has not yet received any petitions for arbitration. By mid-March, 1983, it had 16 cases on file in which siting resolutions have been passed and negotiations are anticipated or underway. One petition for a determination of default was filed, but it was settled informally before it reached the board. To date, no hazardous waste facilities have been proposed.

Minnesota

Minnesota has tried to pick the optimum location for a state-owned site. The facility is to be operated by a private company. The supposed advantage of a state-owned facility is that the long-term responsibility for monitoring a site will rest with a governmental entity (the state) which is likely to exist and have the financial resources to maintain the site many years after closure.

The Minnesota Board members represent state and local interests. Their selection process for sites has narrowed the possible locations to four sites. Once the list of possible sites was narrowed to the final four, local opposition organized in each area. An effective lobbying effort by these groups resulted in state legislation which has put a moratorium on choosing a final site for the last year and a half.

Michigan

In the State of Michigan, a Site Review Board is formed to consider each site. The Board is made up of five permanent members and four temporary members. Of the five permanent members, three are representatives of state agencies: the Department of Natural Resources, Department of Health and the State Police. The other two permanent members are a geologist and a chemical engineer appointed by the Governor. Of the four temporary members of the Board, two are appointed by the governing body of the municipality where the facility is to be located. The remaining two members are local residents appointed by the County Board.

The Department of Natural Resources (DNR) chairs the Board. One of the criticisms of this process is that the DNR is not seen as being neutral in this process. The process has met with some success however. Five facilities have been considered so far. The two facilities which were on the site of a manufacturing process were approved. The three proposed facilities which were to be developed exclusively for the commercial disposal of wastes were not approved.

Colorado

In Colorado, local counties must approve or disapprove proposed sites before they are permitted. The political pressure on county boards has prevented any proposed sites from being approved.

KEY ELEMENTS OF SITING APPROACHES

A review of the siting processes which have been developed in Massachusetts, Wisconsin and elsewhere indicates that there are a number of important factors to consider in developing a hazardous waste facility siting process:
•There must be early and substantive involvement of the public
•The process must provide for a range of interests to have input into the siting process
•The parties involved in a siting process need scientific, technical and procedural support
•The siting process must be efficient and implementable

THE KEYSTONE SITING PROCESS

The Keystone Siting Process is the product of participants in two workshops conducted by the Keystone Center in August and October of 1982. The more than 30 attendees came from a diversity of backgrounds including industry, government, environmental groups, labor and civic organizations. The goal of the workshops was to develop a workable siting process for new hazardous waste facilities in the Galveston Bay Area. The process should be applicable to all of Texas as well as to other states and other types of siting efforts.

Advantages

Establishment of a review committee to facilitate dialogue between applicant and public is the heart of the Keystone siting process. Providing this less formal, prehearing forum to raise and perhaps resolve issues of mutual concern is advantageous to all those interested in a proposed facility: applicant, community and permitting agency. The review committee's goal is to develop a report dealing with local citizen concerns and the manner by which the applicant is dealing with those concerns. Advantages of the committee process are:
•Early citizen input is possible
•Nontechnical issues can be addressed
•Areas of conflict are identified and possibly resolved
•Reliable information is provided to the community
•An informal exchange of information takes place between an applicant and the community

The review committee provides a means of dialogue between the applicant and a duly constituted group representing community interests, thus eliminating the difficulty faced by an applicant who wants public input but is not sure whom to contact. The review process undertaken by the committee permits accommodation of viewpoints during a time period prior to review of the permit application by the respective state agency. This timing allows public involvement in the consideration of a proposed facility earlier than is usually the case.

By working with the public early in the siting process, the applicant has a better chance of eliminating the misinformation that is often generated about a project. The committee also offers both the applicant and the public the opportunity to discuss social and economic issues that may not be admissible in a hearing but are nevertheless of great concern.

The review committee is able to express the concerns of the public to the applicant, thereby providing the applicant with the opportunity to respond to those concerns to the extent possible. Responses might include furnishing data, making changes in the proposed project and making other accommodations which might alleviate some of the public's concerns.

Committee Review

The committee is limited to reviewing a particular facility proposed at a specific site. Committee time and energies should not be expended exploring alternatives to the proposed project, although members will want to know if the applicant explored such alternatives. The committee's charge is not like that of siting boards which actually seek or choose sites for hazardous waste management facilities in some states.

As an entity, the review committee is not to be a party to the public hearing held by the permitting agency. Individual committee members, of course, are not precluded from participation in the hearing process, representing viewpoints of their own or of organizations with which they are associated.

To initiate the Keystone Siting Process, the applicant indicates to the regulatory agency that it intends to file a permit application. The applicant and the regulatory agency then contact those entities involved in appointing committee members. The committee should be selected within 15 days and meet within 21 days of the filing of the notice of intent. The review committee then has until the 90th day to study the proposal and write a report. The process can be extended by mutual agreement between the applicant and the committee.

The applicant's representatives should have sufficient responsibility and authority to deal effectively with the issues raised and make commitments on the part of the company. Failure to assign a person of sufficient stature may be perceived by the committee as an indication of lack of real interest in the process on the part of the applicant.

To streamline the information gathering and communications process, the committee may expect, in many cases, general information on the facility proposal from the applicant in the earlier stages of the process. This is to be followed by more specific technical data as environmental and engineering studies proceed. Throughout the process, all information available to the regulatory agencies will be available to the committee. Questions and answers during committee meetings can be staged from general to specific to maintain a cooperative dialogue.

After the filing of the report, the committee is on "standby" status to respond to changes proposed by the applicant and amend its report as appropriate. If no amendment is made, the committee is dissolved at the initiation of the public hearing. In no case is the committee to participate in the hearing as a "party" to the proceedings, although individual committee members are free to participate in their own right.

Committee Support

Since committee members serve as volunteers, expected expenses are for clerical service and logistical support. However, an applicant may wish to employ professional staff or a professional facilitator. It is also possible that the applicant will want to reimburse out-of-pocket expenses for committee member's mileage, for example, though it is not anticipated that committee work will entail significant expense on the part of the members. The committee will have no financial resources of its own, however, so clerical support at a minimum will be needed. Large expenditures on the part of the applicant would give some the impression that committee members may become obligated to the applicant, so a balance must be struck whatever options are chosen.

The committee develops its report as it chooses, but the applicant will at least pay for clerical help and printing. Copies of the report should be made available to the committee and the permitting agency as well as local libraries and city halls for public use and perusal.

Time Commitment

It is difficult to anticipate a committee's workload in terms of hours. However, within the 90 days that the committee functions, members can expect weekly-to-monthly meetings of two or three hours in length. Members share the writing of the report unless a staff person is used to write the draft. In any case, members review, comment on and edit the final report. Committee members can expect to spend some time on this process; they are not meant to be mere window dressing.

The review committee is constituted to be: (1) open to fact-finding, not locked into positions by external forces such as having financial interest in the project or being an elected official in a town near the site; (2) representative of a breadth of interests; (3) reflective of local concerns; and (4) responsive to its charge of preparing a report. To meet these requirements, it is appointed by, but does not include, elected officials; it includes, but is not dominated by, persons directly affected by the site; it reflects a range of interests and expertise, such as engineering, business, environment; and it is limited to individuals in the general region surrounding the site. In order that the committee be perceived as representing the public, most members need to be known to the "constituency" they represent. For example, the person representing environmental interests should be known to the environmental community.

Committee Membership

The committee should be as small as reasonable, given these principles, to facilitate discussion and the preparation of a report. Given the size, the need for representation and the need to have entities do the appointing, the committee is designed as follows:

Eight regional members appointed by a regional entity and representing various interests:
• Environmental Groups
• Academia
• Industry
• Community Planner
• Public Interest
• Medical

Four members, living within five miles of site, appointed by local mayor(s) and county judge.

A 12 member committee is best suited to developing a written report. Four members come from the exact locality of the project and eight from a somewhat wider region. The ratio between committee members from the immediate vicinity of the proposed site and those from the region is critical in maintaining a balance of concerns and opinions and, therefore, the credibility of the committee. A committee predominantly local would not be seen by the applicant and industry in general as being objective. A committee without local residents would not be seen by the community as reflective of its concerns.

Report

One of the major tasks of the committee, and the ultimate focus of its work, is preparation of a report detailing its work and summarizing its findings. This report, which is submitted to the permitting agency simultaneously with the permit application, is not to be a recommendation of approval or disapproval of the proposed facility. Other than that qualification, the scope of the report is at the discretion of the committee as long as certain elements are included. The report should document discussion of community concerns raised during committee review, including identification and discussion of the following:
• Those issues which were resolved,
• Those issues which were not resolved,
• Those questions which were not answered, including why they were left unanswered.

In addition, the report explains why the committee was established. Members are listed with their associations/backgrounds and how they were appointed. The procedures the committee followed in performing its work are also described.

The committee report is a means of documenting the committee's fact-finding work and of providing information about the proposed facility and related issues. It is not intended to be an additional regulatory burden for the applicant, the permitting agency or the community. Rather, an applicant who chooses to use the review committee process will be creating an advantage to all.

From the public's viewpoint, the report allows the permitting agency to hear its concerns at the same time the staff is examining the permit application. From the applicant's viewpoint, the report shows that efforts were made to listen and respond to public concerns early enough to make improvements to the planned facility. From the permitting agency's viewpoint, the report provides a better understanding of all facets of the proposed facility and its effect on the affected community.

The use of the committee and its report should serve to improve the present siting process. It incorporates the four key elements of siting approaches described earlier. The public is involved early in the process, even before the regulatory agency review. A broad range of interests is represented on the review committee and an even broader range of input is derived from the general public attending committee meetings. The committee receives technical and procedural support during its review of the project. Last of all, this process is efficient (adding only 90 days to the permit process) and implementable. No new laws or regulations are required to use this process in Texas. Ultimately, the Keystone Process should help ensure that the sites permitted in Texas are environmentally sound and able to meet Texas' needs.

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DO COMMUNITY RELATIONS MATTER?:
THE NEW JERSEY PERSPECTIVE

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INTRODUCTION

Why should the Superfund Community Relations Program in New Jersey be of interest to those outside the State? There are several reasons, but the principal one is New Jersey's aggressive policy of identifying and investigating hazardous waste sites and seeking Federal and State funding for remedial action. This policy has put New Jersey at the top of the National Priorities List (NPL) with 85 Superfund sites as of August, 1984 (in a national total of 546 sites) and a likely total of about 100 Superfund sites by the end of this year. These figures do not include State funded sites which should total about 75 in 1984. Michigan is second to New Jersey with 48 sites on the NPL.

The New Jersey figures, when added to those of other Northeast states, two of which are third and fourth on the NPL, i.e., Pennsylvania with 39, and New York with 29 Superfund sites, emphasize the regional context of the uncontrolled hazardous waste site problem in the nation's oldest industrial area. In addition, New Jersey is the most densely populated and industrialized state in the nation, and one in which the petrochemical industry is by far the largest industry.

The State's coastal geography, with porous, sandy soils and highly vulnerable groundwater which provides a substantial portion of the population's potable supplies,[1] is another major factor creating intense environmental pressures and projecting New Jersey's hazardous waste issue to a prominent position. In an interesting juxtaposition to the industrial impression of the State, New Jersey's two second largest industries are tourism and agriculture, both requiring a clean environment in order to thrive. With a high population density and many sites in proximity to population centers, citizens of the state have made cleanup of hazardous wastes one of their greatest concerns.

CHALLENGES IN THE STATE PROGRAM

As a result of all of these factors, New Jersey faces one of the most complex and extensive hazardous waste cleanup challenges of any state. To effectively manage the cleanup of the State's sites, the New Jersey Department of Environmental Protection (NJDEP) developed a comprehensive management plan. The document, called the "Management Plan for the Cleanup of Hazardous Waste Sites in New Jersey 1983-1986," outlines a systematic approach to remedial action.[2] New Jersey's Plan was the first such document in the nation. USEPA is now encouraging other states to develop similar plans.

Although public hearings on the Plan were not mandatory, NJDEP held three such hearings last fall. After assessing extensive public comment, the Department issued a Response Document to clarify public policy and technical issues.[3] In addition to the approximately 175 sites to be addressed in the State's Management Plan, now in revision, New Jersey has tentatively identified more than 1,100 abandoned or improperly managed sites that are potentially hazardous. This large number is primarily because the State has one of the largest concentrations of petrochemical and pharmaceutical industries in the nation. In addition to the threat of human exposure, there is great concern that improper waste disposal may be imperiling the State's ecological resources including sensitive groundwater aquifers, the unique Pinelands and wetland areas, natural resources which must be protected. In fact, New Jersey has recognized the importance of potential natural resources damage and has filed claims totalling $1.27 billion with the Federal government under a special provision of the Superfund Law.

Even before the passage of Superfund, New Jersey began to undertake hazardous site cleanups. Initial remedial actions at sites such as Chemical Control, Goose Farm and A-Z Chemical were completed by 1982 with state Spill Fund monies.[4] Chemical Control was the largest hazardous waste drum removal operation ever undertaken in this country.

With the passage of the Superfund legislation, New Jersey was able to take advantage of prior information needed to qualify sites for federal monies. As a result, New Jersey has developed one of the most advanced cleanup programs in the country.

ACTIONS TO DATE

To date, New Jersey has signed cooperative agreements or contracts with the USEPA for approximately 30 sites to complete feasibility studies, design and construction activities. By the end of Federal FY '84 or the beginning of FY '85, 39 feasibility studies, 16 designs, 6 construction projects and 11 immediate removals expect funding. In addition, the State has investigated 17 major potential dioxin sites and has undertaken emergency dioxin cleanup/containment at four such sites. PCB contamination, which posed an immediate health threat in the City of Perth Amboy, was successfully cleaned up in the summer of 1983. A major cleanup effort under Superfund at the Syncon Resins facility in Kearny was completed in the third quarter of 1984. This project involved the removal and disposal of almost 13,000 drums of chemicals.

By the spring of 1984, a total of 564 homes in northern New Jersey were sampled for the presence of radon gas; 45 homes were contaminated. Remedial actions have thus far been conducted at 22 of the homes.[5]

In 1983, the NJDEP completed the cleanup of 33 small drum dump sites using funds from the State's Spill Fund; an additional

36 small drum dump cleanups should be completed by the end of 1984. Because of the variety and number of New Jersey sites, when the State's experience is quantified it may establish a useful data base for Community Relations as well as general remedial site activities.

COMMUNITY RELATIONS WITHIN THE ORGANIZATIONAL STRUCTURE

The Community Relations Program in Superfund cleanups is resource intensive throughout the complex and often lengthy cleanup process (Tables 1 and 2). The Program presents a significant departure from public participation as it has been commonly practiced under the National Environmental Policy Act (NEPA) of 1970 (amended in 1975) and subsequent Federal and State laws. This difference occurs because the nature of hazardous sites, often literally in people's backyards or affecting drinking water, evokes fears and concerns not exhibited in response to more remote pollution threats.

These concerns must be addressed as directly as possible, and the Community Relations Program is a good vehicle for two-way meaningful communications between citizens and government. Even with the best of intentions, however, it is not usually possible to accomplish site remediation with the speed and definitiveness demanded by an upset citizenry and its elected officials.

Table 1
New Jersey Department of Environmental Protection
Division of Waste Management
Hazardous Site Mitigation Administration

A Community Relations Program at Superfund
Hazardous Waste Sites

As part of the federal/state program of cleanup at hazardous waste sites, a Community Relations Program is conducted to receive local input and to advise local residents and officials about the planned remedial actions at the three major stages of the cleanup: (1) remedial investigation/feasibility study, (2) engineering design and (3) removal/treatment/construction. Local briefings and public meetings are conducted with elected officials and residents and generally take place at:

•The commencement of a remedial investigation/feasibility study to address local concerns early in the process
•The completion of a feasibility study to discuss the alternative courses of remedial action; there is a 30-day comment period after public presentation of the alternatives during which the feasibility study is available in local repositories.
•The engineering design stage to carry out the mandates of the selected remedial alternative.
•The completion of the remedial action

In addition to the more formal activities outlined above, there is generally informal communication with local officials and residents. Depending upon whether the New Jersey Department of Environmental Protection (DEP) or the USEPA has the lead in remedial action at a site, community relations activity is conducted by the relevant State or Federal agency.

In New Jersey, the DEP Community Relations Program is conducted by Grace Singer, Community Relations Program Manager (609) 984-3141/4892. At Region II, EPA, the contact person is Lillian Johnson, Community Relations Coordinator (212) 264-2515.

This is often due to the complexity of hazardous waste problems (which can vary widely from site to site), the number of sites to be addressed (especially in New Jersey), and a relatively new program which is often operating at the cutting edge of technology.

Difficult problems often demand difficult decisions. In this controversial setting, it is critical to set out the goals of the Community Relations Program and understand the importance of public involvement. Clearly, in passage of laws mandating the Federal and State cleanup program, the public, through its elected officials, has already involved itself in a strong mandate for action. Some of the key goals of Community Relations in Superfund can be clarified by asking the following questions:

•How will citizens' concerns about a site be identified, assessed and addressed?

Table 2
Steps Involved in a Major Hazardous Waste Site Cleanup

1. Site Identified and Referred
2. Initial Site Investigation
3. Secure Site
4. Site Analysis Evaluation and Assessment
5. Prioritization
6. Determination of Lead
7. Community Relations Plan Activated
8. Signing of Contract or Cooperative Agreement
9. Hiring of Contractor for Remedial Investigation/Feasibility Study
10. Preparation of Feasibility Study
11. Selection of Remedial Action Alternative
12. Hiring of Contractor for Engineering Design
13. Hiring of Construction/Removal Cleanup Contractor
14. Cleanup Evaluation
15. Contractor Audit and Close Out

•How will accurate information on the problems associated with a particular site be explained and disseminated to local residents?
•How will the remedial alternatives and the proposed solutions be explained to the community?
•How will citizens have adequate opportunity to comment and provide input on ongoing site work before major decisions are made?

In New Jersey, the State used these questions as guidelines and criteria for Community Relations activities with generally favorable results in a program still in its infancy.

In order to meet the challenge of two-way communication with citizens in the intensive New Jersey cleanup program, an Office of Community Relations was established in January, 1983, within the newly formed Hazardous Site Mitigation Administration in the NJDEP (Tables 3 and 4). The Office of Community Relations has five staff members: a Community Relations Program Manager, three Senior Area Coordinators assigned to specific sites and a secretary.

In a team effort, the Community Relations unit works closely with other units within the Hazardous Site Mitigation Administration (HSMA), especially the Bureau of Site Management and other NJDEP technical and legal staff members. This structure has fostered the team approach to public communications on site activity. Technical staff as well as outside contractors conducting the actual field work participate fully in local briefings and public meetings with residents and officials. Thus, citizen questions and comments can be answered directly by those conducting or managing site activity. As a result, such comments are heard with the full flavor and fervor of deeply concerned citizens. This method of operation has conveyed a sense of urgency and added the human dimension which can be lost when dealing with matters in a technical framework only. Likewise, local citizens receive responses directly from those conducting site work.

Effective Community Relations in cleanup activities is seen as important to the overall cleanup effort in New Jersey, and a considerable commitment has been made to it. This is especially true considering the number of New Jersey NPL sites; public meetings take place at night when local residents and officials are available.

Likewise, citizen comments are taken seriously. One notable example of this NJDEP response to citizen concern occurred recently at a site in central New Jersey. Local residents pressed for the installation of a public water system to replace their on-site wells drawing from groundwater contaminated by dumping at the site. USEPA headquarters opposed the new water system, preferring to continue groundwater and well monitoring. The NJDEP agreed with the residents, whose comments and input to the decision-making process were rewarded with a reversal in the USEPA's decision.

In another case, a local committee wanted to be closely included in the initial stages of the feasibility study because members felt they had developed special knowledge about the site. They asked that the Request for Proposal (RFP) include a provision that the

PUBLIC PARTICIPATION

COMMISSIONER
Robert E. Hughey

ASSISTANT TO COM.
B. Davis

DEPUTY COMMISSIONER
Paul Arbesman

EXECUTIVE ASSISTANT
T. Plies

PLANNING GROUP
L. Schmidt

ASSISTANT COMMISSIONER FOR REGULATORY AND GOVERNMENTAL AFFAIRS
Donald T. Graham

Regulatory Affairs
Inter-governmental Operations
Public Participation
Emergency Response Coordination
Harbor Cleanup
Office of Audit

OFFICE OF SCIENCE AND RESEARCH
T. Burke

ASSISTANT COMMISSIONER FOR NATURAL RESOURCES
Helen C. Fenske

ASSISTANT COMMISSIONER MANAGEMENT & BUDGET
Sidney Yikin

ASSISTANT COMMISSIONER FOR ENV. MANAGEMENT & CONTROL
George J. Tyler

OFFICE OF ENVIRONMENTAL ANALYSIS

NEW JERSEY OUTDOORS

PARKS & FORESTRY
R. Myers
Planning, Eng. & Maint.
Parks Mgt.
Forest Fire Mgt.
Forest Mgt.
Natural Lands Mgt.
Youth Services
Parks Law Enforcement
Liberty State Park
Marine Services
Office of N.J. Heritage

GREEN ACRES & RECREATION
H. Lechner
State Land Acquisition
Local Grants Adm.
Recreation & Open Space Res. Plan.
Legal & Support Serv.

FISH, GAME & WILDLIFE
R. Cookingham
Wildlife Mgt.
Marine Fisheries
Shellfisheries
Freshwater Fisheries
Law Enforcement
Endangered & Non-game Species
Mosquito Control
Inf. & Education

COASTAL RESOURCES
J.R. Weingart
Tidelands
Enforce. & Field Serv.
Project Review
Plan. & Development
Coastal Eng.

PERSONNEL & DATA SERVICES
L. Anselmini
Personnel
Data Processing
Affirmative Action
Labor Relations
Env. & Staff Training
Employee Services
Medical Surveillance Program

FISCAL & SUPPORT SERV.
W.J. White
Fiscal & Acct. Oper.
Capital Improvements
Collections & Licensing
Management Services
Special Funds Adm.

WATER RESOURCES
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Water Quality Mgt.
Water Supply & Watershed Mgt. Adm.
Enforcement
Coast. Grants Adm.
Monitoring & Plan.
Geological Survey
Management Services

ENVIRONMENTAL QUALITY
S.G. Kubrtz
Air Quality
Noise Control
Radiation
Pesticides
Laboratories
Enforcement

WASTE MANAGEMENT
M. Sadat
Plan. & Res. Mgt.
Engineering, Permits, & Licensing
Eng. & Field Oper.
Hazardous Site Mitigation Adm.

Table 3
Department of Environmental Protection

Table 4
Hazardous Site Mitigation Administration

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                              Administrator
                           Deputy Administrator

   Administration ─────────────────────┤
                                        │
                                        ├────────────  Contracts Management
                                        │              Joe Wiley—Chief
                                        │
                                        ├────────────  Community Relations
                                        │              Grace Singer—Chief
                                        │
  ┌──────────────┬──────────────────────┼──────────────────────┐
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Bureau of Site Management	Bureau of Environmental Evaluation & Risk Assessment	Bureau of Site Operations	Bureau of Industrial Site Evaluation
A. Farro-Chief	M. Morris—Chief	R. Senna—Chief	A. McMahon—Chief
L. Romino	S. Santora	T. Allen	R. Katz
G. King	R. Predale	F. Metzger	
	J. Goliszewski		

contractor must consult with them and review their extensive files before commencing the feasibility study. Because of their special experience with the site over a long period of time, this request was granted and the contractor did indeed work with the citizen group before proceeding with on-site work.

Citizens can also thwart the legitimate exchange of information between a government agency and local residents when it serves their purposes. One such incident occurred when the Department invited local residents to a three-day public information "open house" at a dioxin site. It was apparent from the unusually low turnout of residents and a demonstration conducted by an organized local group that a show of dissatisfaction, rather than gaining firsthand information, was a local priority.

ISSUES AND QUESTIONS TO CONSIDER

One overriding issue for consideration is adequate staffing and the extent to which the Community Relations function is genuinely integrated into the hazardous site cleanup organization. Is Community Relations considered a frill or is it taken seriously? Is the Community Relations staff part of the internal decision-making process or is it seen as not being involved in the substance of issues causing public sensitivity? Part of the answer to this will be revealed in the background and abilities of the people selected to conduct the Community Relations program.

Related to the above question is the issue of the extent to which there is a team approach to Community Relations with technical and legal staff joining the effort for direct two-way communications between government and the local community.

To what extent will Responsible Party or Private Party enforcement cases be involved in Community Relations? Based on the premise that a local community has the right to know what is being done at a site which is causing adverse effects on public health and the environment, regardless of who is conducting the cleanup, it is essential to develop a workable process assuring effective communication and responsiveness to local citizen concerns in the Private Party cleanup. Such communication should be equal to that of government agency conducted cleanups.

The always sensitive issue of land use is intensified when hazardous waste sites are involved. Because local communities in most states have land use authority while State or Federal agencies have hazardous waste site data, there is a growing information gap. This is especially serious in developing communities where residential subdivisions may be planned near hazardous waste sites. There appears to be very little occurring in the transfer of information between the government cleanup agency and the local land use decision-making body.

Because of the magnitude of this issue in New Jersey, a Land Use Inquiry Program within the Hazardous Site Mitigation Administra-

tion has been established to disseminate information to prospective home buyers and others. An average of 85 such calls are responded to monthly. In order to minimize future problems, a community may take precautions such as establishing a building moratorium within a certain distance around a site, at least until a feasibility study is completed. One county in New Jersey has done this. It appears, however, that most local communities are ignoring or avoiding such decisions primarily because of a lack of information which would legally back up such controversial moves. To avoid the Love Canals or Times Beaches of the future, this issue needs to be addressed generically at the Federal or State level rather than on an ad hoc basis only.

AFTERTHOUGHTS

Public involvement in hazardous waste site decisions will occur in one form or another. It makes sense that such involvement occur early with a goal of informed public input and, ultimately, consent. This ounce of prevention should be seen as a pragmatic step even by those who are impatient with public participation. States should aim for a program which is honest and direct and which may, as an added benefit, encourage an educated public to participate in protecting the environment. Hopefully, hazardous waste site cleanups will not last forever, but there will probably always be hazardous waste to manage, and engineers will always be looking for ways to do that as effectively as possible. Achieving these goals involves everyone.

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2. New Jersey Department of Environmental Protection, *Management Plan 1983-1986 For Hazardous Waste Site Cleanups in New Jersey*, Trenton, NJ, Aug., 1983.

3. New Jersey Department of Environmental Protection, *Response Document for Public Hearing Comments on Management Plan 1983-1986 for Hazardous Waste Site Cleanups in New Jersey*, Trenton, NJ, June 1984.

4. The New Jersey Spill Compensation and Control Act was promulgated in 1977 prohibiting the discharge of petroleum products and other hazardous substances, and requiring that all accidental spills be reported to the New Jersey Department of Environmental Protection. It also imposed a tax on certain transfers of these materials and established a fund for the expeditious cleanup and removal of spills and the payment of damages.

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ELECTRIC REACTOR FOR THE DETOXIFICATION
OF HAZARDOUS CHEMICAL WASTES

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INTRODUCTION

The Huber Technology Group (HTG) of the J.M. Huber Corporation has developed a high-temperature pyrolysis process called an advanced electric reactor (AER) for the permanent detoxification of hazardous wastes. Two series of tests were conducted to demonstrate the effectiveness of the AER for treating soils contaminated with hazardous wastes.

Tests using polychlorinated biphenyls (PCBs) were conducted in September, 1983 to seek USEPA certification under the auspices of the Toxic Substances Control Act (TSCA). This certification was received in May, 1984. A second test series using carbon tetrachloride (CCl_4) was conducted in May, 1984 to provide additional information for a Texas Department of Water Resources permit application in compliance with the Resource Conservation and Recovery Act.

PROCESS OVERVIEW

The HTG process consists of an AER (Fig. 1), plus downstream process gas cleaning equipment. The AER employes a new technology which rapidly heats feed materials to temperatures in the range of 4000 °F to 4500 °F with surface heating rates of 10^5 °F to 10^7 °F/sec using intense thermal radiation in the near infrared range.

The reactants are isolated from the interior reactor wall or core by a gaseous blanket formed on the inside core surface by flowing nitrogen radially inward through the porous core walls. The only feed streams to the reactor are the hazardous waste and nitrogen which is used as a blanket gas. Both solids and gases have reactor residence times of 0.5 to 1 sec at 4000 °F to 4500 °F.

Carbon electrodes are heated electrically and in turn heat the reactor core to incandescence. Heat transfer is accomplished by thermal radiative coupling from the core to the feed materials. The soil contaminants are either vaporized prior to pyrolysis or pyrolyzed in place on the particle surface. Because destruction of the hazardous waste takes place by photon bombardment-induced pyrolysis rather than oxidation, typical combustion products such as carbon monoxide, carbon dioxide and oxides of nitrogen are formed, if at all, in insignificant concentrations. The principal products of soil-borne chlorinated organic waste treatment using the Huber process are chlorine gas, elemental carbon principally in the form of carbon black and a detoxified solid which is free-flowing and granular.

A simplified process diagram of a reactor configured for research purposes is shown in Figure 2. The solid feed stream is introduced at the top of the reactor by means of a metered screw feeder connecting the feed bin to the reactor.

The solid feed is gravity fed through the reactor where pyrolysis occurs. After leaving the reactor, the product gas and waste solids
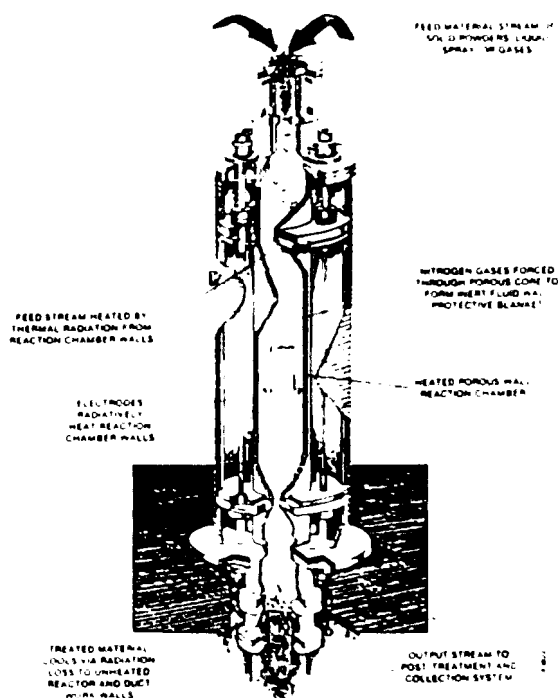
Figure 1
Advanced Electric Reactor

pass through two post-reactor treatment zones (PRTZs). The first PRTZ is an insulated vessel which provides additional high-temperature (approximately 2000 °F) residence times of 0.5 to 1 sec for solids and 5 to 10 sec for gases. Solid and gas-phase resident times for both the reactor and the PRTZ can be independently varied to achieve essentially any desired destruction efficiency. The second PRTZ is water cooled and provides additional residence time (approximately 10 sec). However, its primary function is to cool the molten soil particles below their fusion temperature to avoid coagulation in the treated solid waste bin and to cool the gas prior to downstream particulate cleanup.

Most of the detoxified, solid material exiting the second PRTZ is collected in a solids bin which is sealed to the atmosphere. The majority of fine solids which do not settle out in the bin are removed in the cyclone. The off-gas is then forced by a fan to a bag filter for removal of any remaining fine particulate matter.

Figure 2
Process Configuration for the Test Series

Table 1
Range of Operating Parameters

Parameters	PCB Tests	CCl₄ Tests
Waste Concentration Solid Feed Stack (%)	0.3	0.37-13.76
Waste Concentration - Liquid Feed Stock (%)	NA	99
Solid Feed Rate (lb/min)	15.5-15.8	1.1 -40.8
Liquid Feed Rate (lb/min)	NA	3.3
Reactor Temperature (°F)	4100	3746-4418
Nitrogen Feed Rate (ft 3/min)	145	104.3-189.7

NA = Not Applicable
¹ Standard conditions = 520° R and 1 atm.

Table 2
CCl₄ Test Program

Run No.	Test No.	Reactor Temp °F	N₂ Flow (ft 3/min)	Feedrate (lb/min)	Conc. (%CCl₄)
1	1	3803	184.1	32.8	1.37
2	4	4102	189.7	22.2	1.37
3	5	4104	185.5	5.5	1.37
4	7	3814	104.3	5.5	1.37
5	6	4385	184.1	5.7	1.37
6	3	3799	184.7	6.7	1.37
7	2	3813	184.3	21.9	1.37
8	8	3772	189.3	40.8	0.37
9	15	3808	188.8	3.1	13.76
12	14	3792	189.3	1.1	13.76
10	11	4091	189.2	22.9	0.37
11	9	3746	189.3	21.5	0.37
13	12	4118	189.6	4.6	0.37
14	13	4418	189.4	5.1	0.37
15	10	3782	189.1	4.5	0.37
16	16	3800	190.0	3.3	99¹
17	17	3800	190.0	3.3	99¹

¹ 99% as reported by Vulcan Chemical Company

The process gas cleaning train includes an aqueous caustic scrubber for acid gas, or in this case chlorine, and typically two banks in series of five parallel activated carbon beds, for removal of any trace amounts of residual chlorine and organics. The cleaned off-gas (composed almost entirely of nitrogen and water vapor) is then emitted to the atmosphere. The low process gas flow rate, about 600 ft³/min for the commercial-sized unit, economically allows the degree of cleanup described here.

OPERATING PARAMETERS

The PCB trial burn consisted of four tests conducted over 3 days. In all cases, Aroclor 1260 was mixed with sand and a small amount of carbon black to form a solid waste feed containing approximately 3000 ppm (0.3%) PCBs.

The CCl₄ test series consisted of 17 tests conducted over 4 days. The "waste" material for the CCl₄ was composed of screened, dried soil (less than 35-mesh), activated carbon and CCl₄. Carbon tetrachloride was chosen as a surrogate based on its commercial availability and refractory properties (i.e., it is difficult to destroy by thermal means, resulting in its high position on the USEPA's hierarchy of incinerability).

In pretest screen procedures, the volatility of CCl₄ proved difficult to overcome on a simple soil matrix. The vapor loss from the feed material was unacceptably high. Therefore, activated carbon was added to significantly reduce the effective vapor pressure of the CCl₄ so that relatively high concentrations could be tested in a solid matrix.

The process operating parameters for the two sets of tests are shown in Table 1. The parameters for the PCB trial burn were held essentially constant, while the parameters for the CCl₄ test series were varied over a wide range of conditions. The actual conditions for each CCl₄ test are shown in Table 2.

TEST RESULTS

Sampling, analyses and data interpretation for the PCB tests were performed by Radian Corporation (Austin, TX). Radian also provided analytical support to confirm Huber results for the CCl₄ tests. In each case, the principal organic waste (POW) material (PCB or CCl₄) was sampled in the feed stream and the cyclone outlet. PCBs were also sampled at the stack while CCl₄ was sampled at the outlet to the charcoal beds just prior to the stack. Solid samples were taken at the solid waste bin and baghouse in both sets of tests, and the caustic scrubber and charcoal beds were sampled during the PCB tests. Tests were also conducted to determined fixed gas concentrations at the stack during both sets of tests.

Polychlorinated dibenzodioxins (PCDDs) and furans (PCDFs), volatile products of pyrolysis, HCl and NOx were analyzed for the PCB tests.

Samples were taken using USEPA and NIOSH methods, sometimes with appropriate modifications. Analyses for the POWs were carried out using electron capture gas chromatography (GC-EC) for CCl₄ and capillary gas chromatography-mass spectrometry (GC-MS) for PCBs, PCDDs and PCDFs.

The principal objective of both tests was to determine destruction efficiencies (DEs) and destruction and removal efficiencies (DREs) for the POWs. DEs were calculated using:

$$DE = \frac{R_F C_F - R_G C_G \times}{R_F C_F} \times 100\% \quad (1)$$

Where:

R_F = feed rate (lb/hr)

R_G = process gas rate at cyclone outlet (lb/hr)

C_F = POW concentration in the feed (mass fraction POW)

G_F = POW concentration in the process gas (mass fraction POW)

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while DREs were calculated using:

$$DRE = \frac{R_F C_F - R_S C_S}{R_F C_F} \times 100\% \qquad (2)$$

Where:

R_S = stack gas rate or process gas rate at a point down-stream of the gas cleaning train (lb/hr)

C_S = POW concentration in the stack gas (mass fraction POW)

When feed concentrations based on both weighed proportions at the time of mixing and analytical data were available, worst case values are presented.

Results for PCBs

PCB concentrations in the process and emission streams are shown in Table 3. Results of PCB analyses of the potential wastes from the process, treated sand, baghouse solids and scrubber liquid indicate that for PCBs these streams may be considered nonhazardous for waste disposal. All results were well below 50 ppm, the lower limit set by TSCA for hazardous wastes containing PCBs (40 CFR 761.60, Subpart D). Results ranged from 0.5 ppb to 1 ppb for treated sand, 24 ppb to 530 ppb for the baghouse filter catch and 0.29 ppb to 2.7 µg/l for the scrubber liquid. Results for the activated carbon indicated a concentration of 1 ppb for the charcoal bed inlet post-test sample. However, this result is inconclusive due to the possibility of inordinately high surrogate recovery in the extraction procedure.

Worst case DEs and DREs for PCBs are given in Table 4. DEs range from 99.9995 to 99.99995%. A statistical analysis of the destruction efficiency data employing a Monte Carlo simulation indicates that the ranges of DEs for.the reactor at 95% confidence limits are 99.9995 to 99.999989%. These results indicate that the TSCA requirement of 99.9999% can be closely approached with no downstream cleanup.

Table 3
PCB Concentrations for Process and Emission Streams by GC-MS

	Test 1 9-27-83	Test 2 9-28-83	Test 3 9-29-83	Test 4 9-29-83
Gas Streams (µg/SCM)				
Stack	0.23	0.03	0.10	0.30
Cyclone Outlet	4.1	4.1	21	2.4
Liquid Streams (µg/L)				
Scrubber Liquid	0.29	0.86	0.76	2.7
Preteat Scrubber Liquid	<0.14	NS	<0.14	<0.22
Scrubber Feed Water	<0.14	NS	NS	NS
Solid Streams (µg/g)				
Feed	2530	3100	2710 [a]	2710
Treated Feed	0.0005	<0.0005	0.0006	0.001
Baghouse Filter Catch	0.024	0.29	NS	0.53 [b]
Charcoal Bed (µg/g)	NS	NS	NS	0.001 [c]
Preteat Charcoal (µg/g)	0.003	NS	NS	NS

Standard Conditions = 528 °R, 1 atm.
NS = Not Sampled
Values are not blank subtracted.
a. Single feed batch used for Tests 3 and 4
b. Cumulative for Tests 3 and 4
c. Cumulative for Tests 1 and 4

Table 4
Destruction Efficiencies and Destruction and Removal Efficiencies for PCBs

Parameters	Test 1	Test 2	Test 3	Test 4
Destruction Efficiency (%)	99.99990	99.99992	99.9995	99.99995
Destruction and Removal Efficiency (%)	99.999995	99.9999994	99.999998	99.999993

DREs differ from DEs; the product gas has passed through a baghouse, caustic scrubber and charcoal beds prior to entering the stack. In all cases, the DREs easily exceeded the 99.9999% TSCA criterion for PCB incineration (40 CFR 761.70 Subpart D). DREs ranged from 99.999993 to 99.9999994%. A Monte Carlo simulation of the DRE data for the process indicates that at 95% confidence levels, the expected efficiencies range from 99.999991 to 99.9999997%.

PCDDs and PCDFs were analyzed in cyclone outlet samples using selected ion monitoring (SIM) GC-MS. The results of these analyses show that the PCDDs and PCDFs were below the detection limits of from 0.03 µg/SCM to 0 .06 µg/SCM. For volatile organics, toluene at a maximum concentration of 180 µg/SCM (45 ppb) and three unknown hydrocarbons at lower concentrations were detected in 3 out of 10 stack samples. No volatile halogenated organics were detected in the stack gases at detection limits of approximately 1 ppbv to 20 ppbv.

Particle loading analysis yielded a maximum loading of less than 7.1 mg/SCM at the stack. This is well below the 180 mg/SCM New Source Performance Standard for incinerators (40 CFR 60, Subpart E). Because of low concentrations, NOx data showed considerable scatter. However, the highest average NOx concentration was 16 mg/SCM (8.8E- 3 lb/hr). No applicable NOx standard for incinerators is available for comparison. Chloride analyses for the stack emissions yielded concentrations that were below detection limits in all cases with a maximum concentration of less than 0.016 mg/SCM (<8.8E-6 lb/hr). The maximum chloride emission rate was well below the criterion of 4 lb/hr for hazardous waste incinerators (40 CFR 264). Fixed gas analyses of the stack gases by Orsat indicated a minimum of 96.8% N_2 with typical concentrations greater than 99.5% and CO_2 concentrations less than 0.2% (detection limit) in all cases.

Results for CCl₄

On May 18, 21, 22 and 23, 1984, CCl_4, a highly refractory hazardous waste surrogate, was used as a contaminant on a solid substrate. Soil with activated carbon added was used in 13 tests, activated carbon alone in two tests and a commercially pure liquid in two tests.

The four primary test variables (Table 2) were: (1) reactor temperature (three levels—nominally 3800°, 4100° and 4400 °F); (2) feed rate (four levels—nominally 5, 20, 33 and 40 lb/min); (3) concentration of CCl_4 (four levels—nominally 0.5, 2, 20 and 100%): and (4) residence time—a function of N2 flow and temperature (two levels—nominally 3 and 6 sec).

The basic Huber and Radian analytical data are found in table 5. Tests 16 and 17 were conducted with CCl_4 as a pure liquid feed. The relatively high quantity of CCl_4 at the cyclone outlet indicates a lower DE than with the soil-based feed. However, CCl_4 levels at the stack inlet are almost indistinguishable from those of other soil-based tests. This clearly demonstrates the intrinsic safety features of the AER to handle process upsets and incomplete destruction if and when they occur.

Fixed gas data (5 tests) indicated greater than 98.9% N_2 in all cases, with O_2 ranging from 0.3 to 0.8% and CO_2 from undetected to 0.6%.

Table 5
CCl₄ Concentrations for Various Process Streams

Test No.	Feed (%)	Treated Material (µg/g)	Bag House Filter Catch (µg/g)	Cyclone Outlet (µg/scm)		Cyclone Outlet (ug/scm)	
				Huber	Radian	Huber	Radian
1	1.24	0.69	—	0.03	0.02	0.002	0.0007
2	1.14	0.47	—	0.008	--	0.002	--
3	1.34	--	—	0.006	--	*	--
4	1.75	0.47	--	0.15	0.12	0.007	0.0004
5	--	--	--	0.05	--	<0.0002	--
6	--	--	--	0.01	--	0.0007	--
7	--	0.07	24.10	0.06	--	0.0004	--
8	0.28	0.14	4.20	0.008	0.008	0.002	0.001
9	0.46	--	—	0.004	0.004	<0.0009	<0.0007
10	--	0.56	1.33	0.0008	--	<0.0004	0.0007
11	--	—	--	0.003	--	<0.0004	--
12	--	--	--	0.02	--	<0.0004	--
13	--	--	—	<0.002	--	<0.0004	<0.0004
14	--	--	--	0.002	--	<0.0008	--
15	13.76	0.18	—	0.02	--	<0.0008	--
16	--	--	--	3300	--	0.005	--
17	--	—	—	5700	--	0.003	--

*The sampling pump failed while taking this sample.
-- = not sampled.

Table 6
Destruction Efficiencies (DE) and Destruction Removal Efficiencies (DRE) for CCl₄

Test No.	DE (%)	DRE (%)
1	99.999920	99.999992
2	99.999956	99.999990
3	99.999908	*
4	99.999240	99.999963
5	99.999018	>99.999996
6	99.999749	99.999987
7	99.999296	99.999996
8	99.999914	99.999981
9	99.999922	>99.999983
10	>99.999924	>99.999961
11	99.999952	>99.999992
12	99.998355	>99.999961
13	>99.999873	>99.999965
14	99.999978	>99.999991
15	99.999916	>99.999997
16	98.3	99.999997
17	97.1	99.999999

*Sampling pump failed.

DEs and DREs for CCl₄ are shown in Table 6. DEs were 99.9999% or greater in most cases and 99.999% or greater in all cases except Tests 12, 16 and 17. The Radian crosscheck results supported these conclusions.

The DRE results clearly demonstrate the extremely high treatment capabilities of the HTG AER process. No test yielded results below 99.9999% DRE. This is over two orders of magnitude better than RCRA minimum requirements for hazardous waste incinerators. Again, agreement between DREs calculated from the Huber results are supported by the Radian crosschecks, and both support the previous statement of high AER treatment capability.

AER APPLICATIONS

Numerous applications exist for the AER including: hazardous organic waste treatment; metal refining operations; production of powdered refractories, fillers, glass fibers and other ceramics; conversion of wastes to syngas; and vitrification of inorganic hazardous wastes and low level nuclear wastes. In hazardous waste treatment, this process is uniquely suited for:

• Treatment of low Btu content hazardous materials; i.e., contaminated soils, pure PCBs and other heavily halogenated hydrocarbons

• Treatment of extremely hazardous materials; i.e., dioxins, PCBs and nerve gas

• "In-process" treatment of hazardous by-products from chemical, metallurgical and ceramical processes, frequently with profitable raw material recovery

The process offers a number of unique advantages including: transportability; noncontact reactor design; extremely high process temperature with relatively long residence times which result in very high treatment efficiencies; essentially no stack or fugitive emissions; intrinsic safety features; and the ability to detoxify wastes in a pyrolytic atmosphere, thereby avoiding products of oxidation such as dioxins and furans.

HTG plans to use its Borger, Texas, 12 in. pilot-scale AER in a number of research activities including: establishing DEs and DREs and treatment costs as a function of operating conditions and process configuration; developing practical feed pretreatment processes; process development for various "in-process" applications; and treatment feasibility testing with specific wastes from potential treatment sites (i.e., Love Canal, S-Area and other Superfund sites). A commercial transportable unit with a throughput of 20,000 to 30,000 tons/year is being designed for on-site soils detoxification work. It is scheduled to begin commercial operation in mid-1985. Larger units are also being considered depending on demand.

THE ECONOMICS OF GROUND FREEZING FOR MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

Artificial ground freezing is not a new technology. There exists a 100-year tradition of shaft sinking in which ground freezing has been used. The increasing application of ground freezing for civil engineering projects in recent years is mainly due to the following advantages:[1]

•In principle, ground freezing can be used in all types of soils
•Ground freezing is a very flexible construction method which can meet many boundary conditions and requirements
•Very little or no environmental concern is associated with the method when dealing with soils for civil engineering purposes

During ground freezing, the temperature of the soil water is lowered below the freezing point. The freezing temperature of soil solutions is not 32 °F as for pure water, since dissolved ions in the soil lower the freezing point. However, empirical relations exist that quantify the freezing point of soils.[2-5] It might be argued that the freezing point of hazardous waste is much lower than that of soil systems. While this is a valid point, artificial freezing is done in the soil surrounding the hazardous waste and not in the waste itself. Therefore, uncontaminated soil data are usable. When the soil temperature is lowered to the freezing point, important changes begin to occur in soil properties. The strength of the soil is substantially increased and the soil permeability is decreased. The potential use of ground freezing in hazardous waste remedial action is based on these two important points. The increase in soil strength upon freezing means that a frozen zone of soil can be formed around or underneath a hazardous waste site or between the site and an uncontaminated environment without adding concrete, slurry walls, steel sheet pile walls or grout for injection. Also, the frozen zone of soil becomes practically impermeable.

The first use of artificial freezing was in 1862 in Swansea, Wales. The purpose was to support a mine shaft project used for mine production, material and personnel access, ventilation and emergency escape exits.

In 1883 Poetsch patented a method of ground freezing with cooling pipes[6] which, with some modification, is still in use. In this method, vertical drill holes with standard steel casings are uniformly spaced along the desired freezing line. Bore holes accommodate 3 to 6 in. diameter pipe. Standard black pipe half the bore diameter is inserted in each casing, forming two concentric cylinders. A header or manifold system provides coolant such as calcium chloride brine at −4 °F to the interior pipe, with the return line being the outer casing. The manifold system runs along the freezing line to reduce thermal losses. A self-contained refrigeration system pumps coolant around the freezing loop.

An open loop system using an expendable coolant such as liquid nitrogen (LN_2) has the advantage over brine freezing because it achieves a much lower temperature (− 321 °F) in a very short time. Therefore, LN_2 is useful in emergency cases where time is limited. Also, the fast freezing of contaminated soil by LN_2 will result in immobilization of chemicals, as the soil water (with contaminants) will freeze in situ.[7] Brine freezing, on the other hand, has the advantage of freezing the soil walls in a more regular shape. Temperature measuring instrumentation is appropriately placed for monitoring the progress of the freeze front. A schematic representation of the two freezing methods is shown in Figure 1.
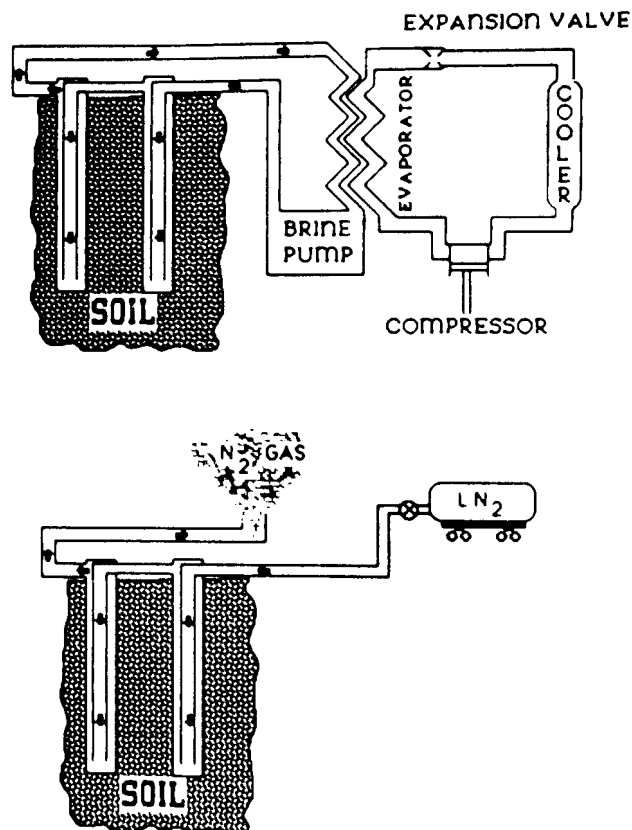
Figure 1
Soil Freezing Methods — a) brine; b) LN_2

According to Braun and Nash,[8] the use of ground freezing in the mining industry has advantages over conventional methods (dewatering, grouting, slurry walls, caissons):

●It does not require extensive geological data
●It serves several temporary functions such as support of an excavation, groundwater control and structural underpinning
●It is adaptable to practically any size, shape or depth
●Excavation can be kept unobstructed as no bracing or sheathing is usually required
●It does not disturb the groundwater quantity or quality
●It is environmentally acceptable, as no chemicals will be added, and there is less disturbance to the site

Through 1978, more than 200 deep mine shafts had been driven by artificial soil freezing.[9]

In addition to its use in the mining industry, ground freezing has been used for construction of open excavations and deep unsupported construction trenches. For example, it was used during the construction of subways in Moscow and in Zurich.[10,11] About 70 inclined tunnels and over 30 excavations were made by soil freezing. The use of ground freezing in the Moscow project saved 700 tons of metals and 650 yds[3] of timber, and the project was completed 11 to 12 months early.[10,11] This project was circular, with a 130 ft

In North America, artificial freezing has been used since 1888.[8] In 1959, it was necessary to enlarge a twin railroad tunnel in Montreal. Construction problems arose because of the presence of a plastic layer of clay in the soil and because the tunnel was located under the city and ran beneath service pipelines and two large buildings. Artificial soil freezing was successfully utilized in this project.[12]

In 1964, liquid nitrogen (LN_2) was used for artificial soil freezing in Argenteuil, France. In this project a collector sewage pipe housed in a tunnel broke. The sewage flooded the tunnel and seeped to a nearby stream. The influx was stopped by circulating LN_2 through 25 freezing probes. A concrete wall was later constructed between the polluted area and the fresh water stream.[13]

The economics of ground freezing as a means of hazardous waste containment are discussed below. These cost analyses are based on existing construction practices and proven freezing technologies. The data needed to calculate thermal parameters required for technical and economic assessments of ground freezing are routinely obtained during the geotechnical and hydrologic site examinations. This site-specific information is required to evaluate the technical feasibility of the containment alternatives.[14]

The thermal data are obtained primarily from soil texture, moisture content and temperature measurements. The specific heat of soils depends primarily on the water content since the volumetric heat-capacity ratio for water to most dry soils is about 5. The thermal conductivity of coarse-grained soils is significantly larger than that of fine-grained soils. Both saturated soil types exhibit a decrease in thermal conductivity with increasing water content.

Moisture content measurements determine the latent-heat energy requirements and establish whether or not the soil is saturated. A saturated soil system is desirable for an impermeable frozen barrier and is assumed throughout this analysis. Lunardini[15] provides extensive data relating these site examination measurements to soil thermal properties. As an example, Figure 2 displays thermal conductivity as a function of moisture content for a fine-grained saturated soil.

ECONOMIC CONSIDERATIONS

There are no additional site examination costs for the ground freezing treatment, as opposed to alternate containment modes. Therefore, the economics of the site-specific investigation (i.e., geotechnical, hydrologic and lab filter-cake permeability testing) are unchanged from the USEPA estimate of $20,000 - $80,000.[14]

Unit costs for most of the equipment required for ground freezing are shown in Table 1. Equipment mobilization involves transport of the boring rig, refrigeration units, piping and site-

FINE-GRAINED SATURATED SOILS
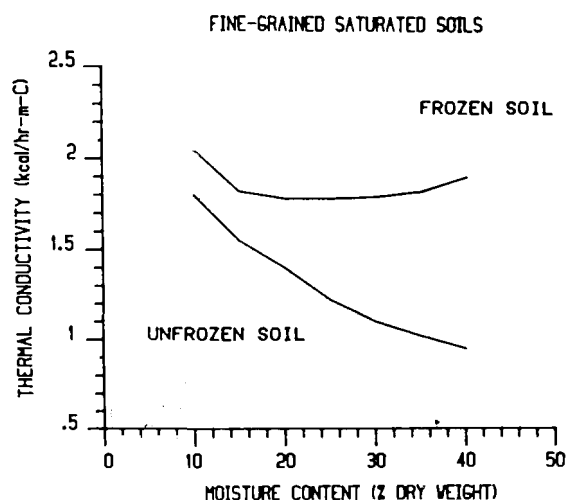
Figure 2
Thermal Conductivity as a Function of Moisture Content
for a Fine-Grained Saturated Soil (Lunardini, 1981)

clearing equipment. The site preparation requirements for ground freezing are relatively low. The barrier must be saturated with water if the soil moisture content is inadequate. Land clearing is necessary for equipment access along the freezing route. Excavation and heavy duty land clearing are not usually required for ground freezing. Capital costs include drilling and pipe system expenses. The drill-hole steel casings are not recovered at the completion of the project. However, the header system and interior cooling lines can be rented on a monthly basis. Energy requirements involve rental of the refrigeration units, electrical consumption and expendable coolants if used.

Table 1
Unit Costs for Ground Freezing Equipment and Supplies*

	Daily Output	Total Costs ($) 100/unit		
1. Mobilization[17] Dozer, drill rig, refrigeration unit over 100 miles add		1/mile/unit		
2. Clear wooded lot (trees ◁10 in dia.)[17]	0.7 A+	2450/A		
Grub stumps and remove	1.5A	1100/A		
Dozer medium duty clearing	3,000 Y^2	0.31/Y_2		
3. Header pipe system[17]	Month-	1	2	3
70 GPM 3 in dia.	rental costs	1.40	0.85	0.65
150 GPM 4 in dia.	per L.F. of	1.60	0.90	0.70
400 GPM 6 in dia.	pipe	2.50	1.00	0.75
4. Well hole drilling[18]	100 L.F.			
4 in ID steel casing		9/L.F.		
5 in ID steel casing		12/L.F.		
6 in ID steel casing		15/L.F.		
Drive shoe		75/well		
5. Black steel pipe[18]				
2 in dia.**		0.22/L.F./M		
3 in dia.		0.36/L.F./M		
6. Self-contained refrigeration units[16]				
7 ton refrigeration		150/day		
110 ton refrigeration		1.23/week		
7. Liquid N_2[19]		1.23/100 ft[3]		
8. Electricity		0.10 per kwh		

* All prices include parts, labor, operating and profit for subcontractor unless otherwise noted.
** 2 in. pipe ($5.20/L.F.) — Rent at 2 yr. writeoff = 0.22/L.F./M
   3 in. pipe ($8.66/L.F.) — Rent at 2 yr. writeoff = 0.36/L.F./M
+ A = acre, Y^2 = sq. yard, L.F. = lineal foot, M = Month

The time constraint for the frozen wall plays a primary role in the cost estimate. Mechanical refrigeration units rated at 5-110 tons of refrigeration are readily available.[16] These units provide the manifold system with reusable coolant at $-4\,°F$ when operated within their appropriate capacity range. Expendable LN_2 is available in large quantities when the demand for a rapid freezing front is required. For this system, the expanded N_2 gas is vented directly to the atmosphere. The refrigeration units are replaced with LN_2 tanks and control valves that regulate the LN_2 flow based on the vent temperature.

Sanger and Sayles[20] provide a sound methodology for thermal computations of frozen ground. Their energy requirements and freezing time estimates are somewhat more conservative than those predicted by finite element simulations and actual field measurements.[21, 22] However, for this preliminary economic analysis, their predictions are appropriate. Sanger and Sayles predict the expenditure of energy based on reasonable assumptions about the heat transfer process in the soil. The energy per unit length, Q, time, t and power per unit length, P, required to freeze a cylinder of radius R is a function of the soil thermal properties, thermal conductivity, k, thermal capacity, c, latent heat of fusion, L and the temperature difference between the coolant and soil.[20]

Ignoring second-order effects, they derived the energy estimate:

$$Q = \pi R^2 \left[\frac{(a_r^2 - 1)}{2\ln(a_r)} c_2 T_2 + L + \frac{c_1 T_0}{2\ln(R/r_0)} \right] \tag{1}$$

where the first term in brackets accounts for the energy required to reduce the unfrozen soil temperature from T_2 down to freezing. The second term of Equation 1 is the energy associated with the transformation from unfrozen soil to frozen soil at the freezing temperature, i.e., the latent heat of fusion, L. The last term describes the energy used in reducing the frozen soil temperature from freezing to the refrigeration temperature. The time required to freeze the column to a radius R is:

$$t = \frac{R^2 L_I}{2k_1 T_0} \left(2\ln(R/r_0) - 1 + \frac{c_1 T_0}{L_I} \right) \tag{2}$$

and the power requirement is:

$$P = \frac{dQ}{dt} = \frac{2\pi k_1 T_0}{\ln(R/r_0)} \tag{3}$$

where the symbol definitions and units are as given in Table 2. The total power requirement is larger than that expressed in Equation 3 due to inefficiencies in the refrigeration system. A 15% thermal loss along the header system is assumed. The refrigeration system is conservatively rated at 0.21 tons of refrigeration per horsepower.[6] The energy required for brine pumps and cooling fans is estimated at 20% of the refrigeration load.

The economics for ground freezing and slurry wall construction are based on a 3 ft wall thickness. Once the soil columns merge according to Equation 2, Sanger and Sayles approximate the frozen soil thickness at 0.79 times the soil column diameter. If this wall thickness is less than 3 ft, the wall increases in thickness as a planar front according to separate equations published by Sanger and Sayles.[20] This design thickness is a limitation of the slurry wall excavation equipment and not a result of structural support or permeability requirements; nevertheless, the authors have used it for the frozen wall to establish a baseline comparison.

The energy and time requirements are proportional to the square of the radius of each cylinder (Eqs. 1 and 2). Initially, one might expect an economic advantage for a thin-wall construction via multiple cylinders of small radius. However, the final cost analysis shows

Table 2
Symbol Definitions and Units

a_r	A factor which when multiplied by R defines the radius of temperature influence on the freeze pipe. Dimensionless—usually $3 < a_r < 5$.[20]
c_1, c_2	Volumetric specific heat capacity for frozen and unfrozen soils, respectively. Btu/ft3/°F
k_1, k_2	Thermal conductivity for frozen and unfrozen soils, respectively. Btu/hr/ft/°F
L	Latent heat of fusion. Btu/Ft3
L_I	Latent heat effects plus heat requirements of unfrozen soil.[20]
P	Power per unit length of pipe. Btu/hr/ft
Q	Freezing energy per unit length of pipe. Btu/ft
R	Radius of frozen soil column. ft
r_0	Radius of freeze pipe. ft
T_2	Absolute value of (unaffected soil temperature—freeze temperature) °F
T_0	Absolute value of (pipe temperature—freeze temperature). °F
t	Time to freeze soil to a radius of R. s

intermediate-radius cylinders as the most economical due to the reduced number of drill holes required. In addition to the economic gains, a thicker wall has greater seepage resistance, although this is unquantified in this analysis.

Once the frozen wall is formed, a reduced refrigeration load maintains the wall while the contained hazardous waste is being treated or removed for proper disposal. The maintenance economics are conservative as they are based on a wall that continues to increase in thickness. The maintenance power requirements is half that of Equation 3 for soil columns having diameters 1/.79 times the design thickness. (The factor 1/2 enters because each soil column has merged with adjacent frozen columns.) This power requirement coupled with equipment rentals and manpower comprise the maintenance expense of the wall. A substantial amount of time exists after the refrigeration unit is removed due to the latent heat stored in the frozen wall. If the wall facial area is large compared to the thickness, a one-dimensional melt analysis is applicable. Carslaw and Jaeger[23] provide an analytic solution for a simplified one-dimensional melt problem. The region x 0 is initially solid at the melting temperature. The wall face at x = 0 is raised to a constant temperature above the melting temperature. The position of the frozen/unfrozen plane is given by

$$X = 2\lambda(t \, k_2/c_2)^{\frac{1}{2}} \tag{4}$$

where the numeric constant, λ, is a function of the thermal soil properties. For the frozen wall situation, melting occurs on both sides. Rearranging Equation 4, the time required to melt the wall (i.e., X = 1.5 ft) can be calculated using:

$$t = \frac{X^2}{4\lambda^2(k_2/c_2)} \tag{5}$$

The specific heat capacity of the frozen wall increases the actual wall energy storage. However, this additional energy storage was not included in the melting analysis.

EXAMPLES

Hypothetical Hazardous Waste Site

The hypothetical situation is a 10-acre hazardous waste site located 150 miles from the drilling and refrigeration contractors. The USEPA Handbook for *Remedial Action at Waste Disposal Sites* recommends that a slurry wall 1000 ft long and 3 ft wide be placed down to the bedrock on the up-gradient side of the site. The

depth to the bedrock averages 40 ft. USEPA slurry wall estimates and the authors' artificial ground freezing estimates for saturated coarse quartz sand initially at 45 °F are shown in Table 3. The cost has been plotted as a function of freezing rod spacing in Figure 3. It can be seen in Table 3 that artificial ground freezing is an acceptable solution, provided the containment time requirement is short (less than 135 days). Thereafter, the daily maintenance costs make the ground freezing alternative unattractive.

Table 3
Slurry Wall and Frozen Ground Construction Estimates

Activity	Unit Costs*	Total Costs
A. SLURRY WALL[14]		
Testing—geotechnical, hydrologic and lab filter cake permeability	N.A.	$ 20,000-$ 80,000
Equipment Mobilization—hydraulic backhoe, bulldozer, slurry mixer, etc.	N.A.	$ 20,000-$ 80,000
Slurry trenching, excavation, mixing and backfilling	$45-$70/Y^2	$200,000-$310,000
Maintenance	---	---
Overall	N.A.	$240,000-$470,000
Average	---	$355,000
B. ARTIFICIAL GROUND FREEZING		
Testing—geotechnical, hydrologic and lab filter cake permeability	N.A.	$ 20,000-$ 80,000
Equipment Mobilization, clear, 4 in drill casing	$21.4/Y^2	$ 95,000
Rent—refrigeration, 4 in header, 2 in pipes, manpower	$6.9/Y^2	$ 30,500
Energy consumption	$5.7/Y^2	$ 25,500
Maintenance	$0.31/Y^2/day	$1400/day
Extra melt time due to latent heat (numeric constant in Eq. 4 = .1614		25 days
Overall**	Maintenance + $171,000-$231,000	
Average	Maintenance + $200,000	

*See Table 1 for unit costs. Y^2 is sq. yards for depth x linear dimension. A 3-ft wall thickness is assumed in all calculations.

** Figure 3 at 18 day freeze time with 214 drill holes.

Examining Figure 3, one can see that as the drill spacing becomes tighter, the fuel costs, equipment rentals and time for wall completion are reduced. These results agree with Equations 1 and 2. A tight drill spacing yields small frozen soil column radii. This reduces the overall energy requirement and permits use of less expensive refrigeration equipment. The drawback of the close drill spacing is the expense associated with the drilling operation. The lineal footage of piping, a drive shoe for each well drilled and the labor charge per vertical foot drilled overwhelm all other economic parameters.

Chemical Spill

Consider the situation where a derailed chemical car disperses a toxic substance over an area adjoining a railroad track (Fig. 4). Surrounding towns impose a time constraint on the chemical and transportation companies for containment of the waste. A preliminary week is required to define the hazardous spill and obtain general site test results.
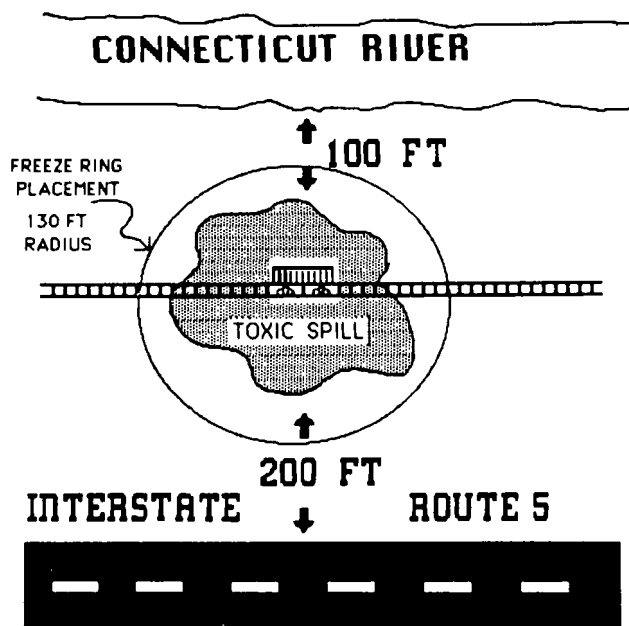
Figure 4
Hypothetical Train Car Toxic Spill — Plan View
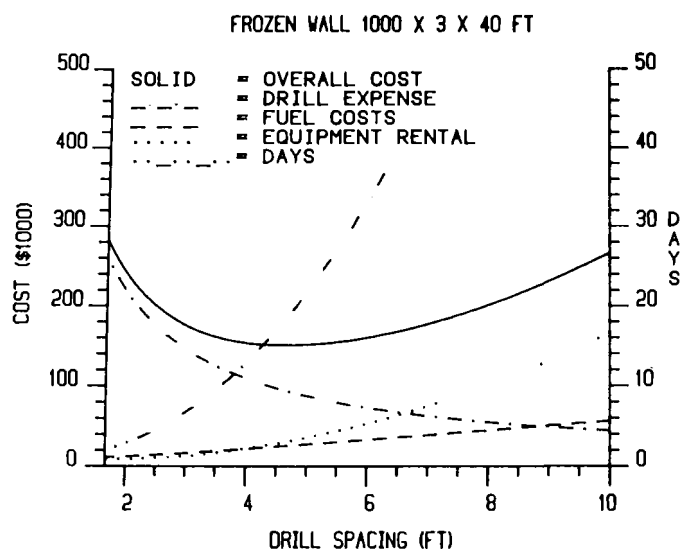
Figure 3
Economic Overview for EPA Test Case
(1000 x 40 x 3 ft)
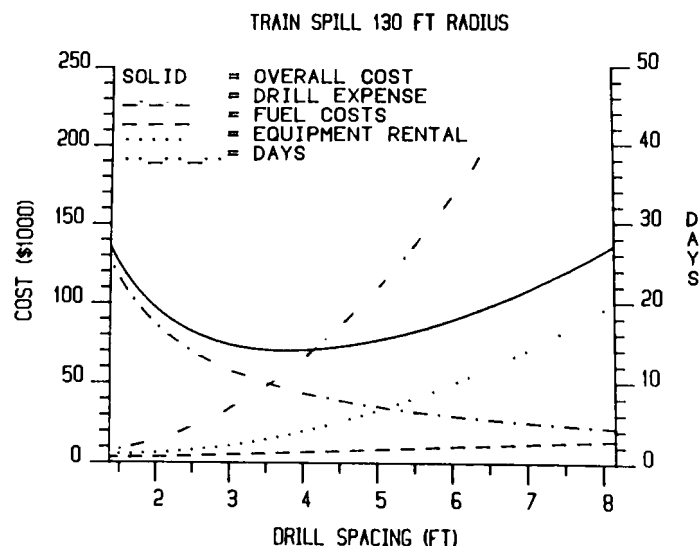
Figure 5
Economic Overview for Train Car Spill Example

COARSE-GRAINED, HIGH MOISTURE SYSTEM
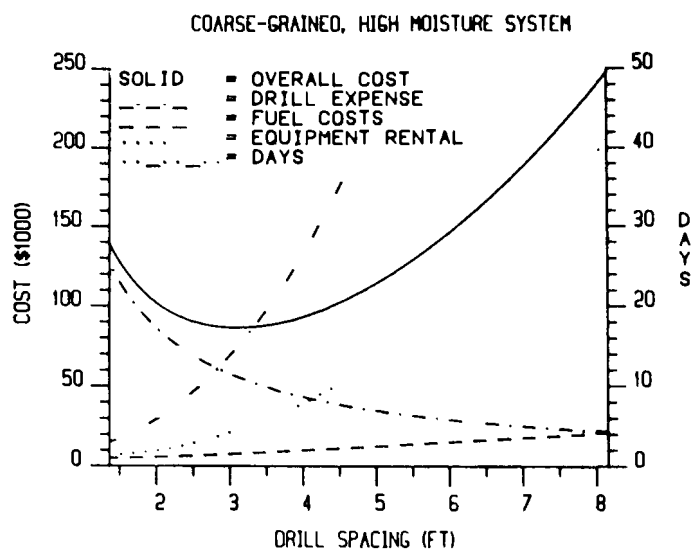
Figure 6
Economic Overview for Coarse-Grained, High Moisture Soils

FINE-GRAINED, HIGH MOISTURE SYSTEM
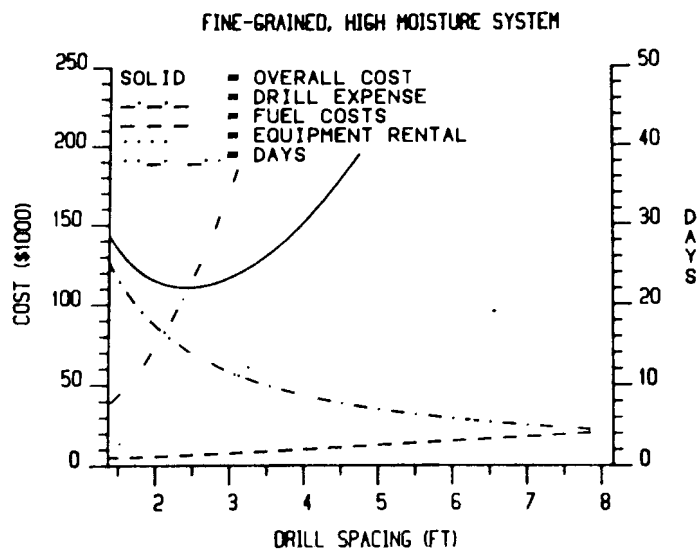
Figure 8
Economic Overview for Fine-Grained, High Moisture Soils

COARSE-GRAINED, LOW MOISTURE SYSTEM
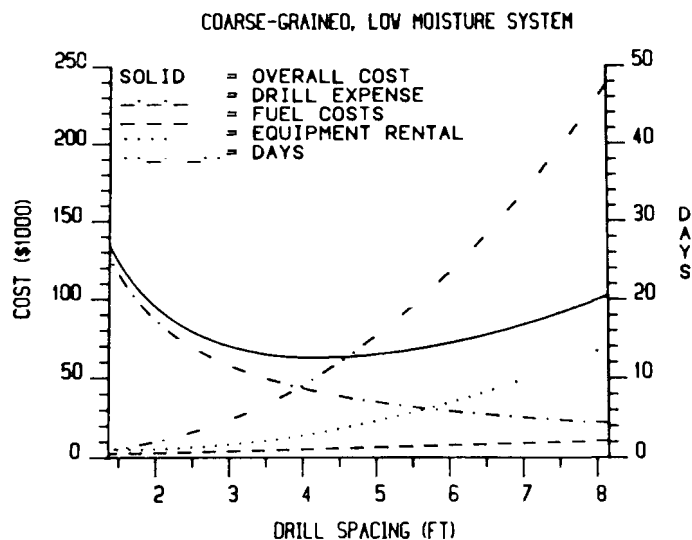
Figure 7
Economic Overview for Coarse-Grained, Low Moisture Soils

FINE-GRAINED, LOW MOISTURE SYSTEM
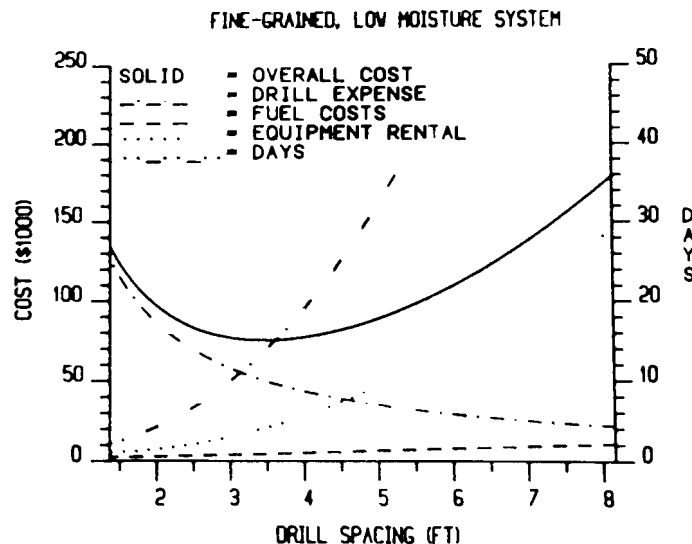
Figure 9
Economic Overview for Fine-Grained, Low Moisture Soils

Initial drill samples estimate the barrier depth at 15 ft. Assuming the pollutant diffuses horizontally 1 ft/day, the frozen wall is planned at a radius of 130 ft. This information is used to generate the economic overview presented in Figure 5. The optimum cost design calls for a 3.8 ft drill spacing with a 12-day freezing time. If there is insufficient time remaining to freeze the soil before the time constraint is reached, the drill spacing is reduced with an associated increase in overall costs.

Discussion

The thermal properties used in both of the above examples are those determined by O'Neill[1] for saturated quartz sand. The following cases show the economic and time dependence as a function of thermal parameters based on the train spill example geometry. Using data from Lunardini[1] for saturated soils the full range of soil texture and moisture content effects is examined. The optimum design configuration for the various spills is given in Table 4 while the economic overview of each soil system is plotted in Figures 6 to 9.

The results show that increasing the soil moisture content increases the time required to establish a frozen wall. For these high-moisture soils, mechanical refrigeration would need a tight drill spacing to satisfy the same time constraints as in the train car spill case. However, an expendable LN$_2$ system with a 2.5-ft drill spacing establishes an impermeable barrier within eight days of pumping. This compares to a 22-day refrigeration time for a mechanical system under the same conditions of saturated fine-grained soil with a 40% moisture content (Fig. 8). The LN$_2$ frozen wall assumed a $-75\,°F$ vent temperature for the freezing pipes.

The economics of expendable coolants are variable and generally hard to quantify. Veranneman and Rebhan[14] approximate LN$_2$ consumption at 800 kg of LN$_2$ per m^3 of frozen soil. Stoss and Valk[15] approximate the LN$_2$/brine expense ratio at 2 for large freezing projects (> 700m^3) with maintenance periods exceeding 30 days. Consequently, once the LN$_2$ system establishes the barrier, a mechanical refrigeration unit maintains the system during the waste treatment process.

Table 4
Thermal Parameter Effects on Costs and Time Performances for Saturated Soils

Saturated Soil Texture	k_1 $\frac{cal}{cms°C}$	c_1 $\frac{cal}{cm^3°C}$	c_2	L $\frac{cal}{cm^3}$	Moisture Content % of Dry Weight	Cost $/yard^2$ of Perimeter	Time Days	Figure
Coarse Grain	.00653	.44	.71	40	40	64	15	6
	.00972	.44	.54	15	10	46	10	7
Fine Grain	.00264	.47	.72	40	40	82	22	8
	.00472	.46	.56	15	10	56	14	9
O'Neill[25] Thermal Properties	.009	.398	.589	23.5	-	-	-	3,5

Cost estimate based on a wall 816 ft. round, 15 ft. deep.

For comparison: Slurry wall[24] $75/y^2$ of wall

An alternate economic overview is presented in Figure 10 in which a constraint on the maximum allowable freezing time has been introduced. The minimum cost for given geometric and thermal conditions is plotted as a function of maximum allowable freezing time; t* is the optimal (least cost) freezing time obtained from the unconstrained Figure 5. If the time constraint is greater than t*, then the optimum spacing is selected. For time constraints less than t*, the cost rises following the curves as in Figure 5. Figure 10 was constructed using the train spill data.

CONCLUSIONS

Ground freezing as a means of hazardous waste containment can be a cost effective operation for a large range of thermal conditions. Soil parameters were shown to significantly affect the cost analysis. Fine-grained soils with high moisture retention can double the overall barrier expense compared to that of coarse-grained soils with low moisture characteristics. However, regardless of the thermal conditions presented herein, the drilling operation was the primary cost factor whenever a time constraint less than or equal to the optimum spacing was imposed. The economic advantage of ground freezing over alternate barrier technologies is limited to temporary treatment sites due to the thermal maintenance expense.

TRAIN SPILL 816 X 15 FT

Figure 10
Cost and Drill Spacing as a Function of Time

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THE ROLE OF ADSORPTION AND BIODEGRADATION IN ON-SITE LEACHATE RENOVATION

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INTRODUCTION

In a number of recent papers, the authors have described experiments with high-strength, hazardous industrial wastewaters.[1,2,3,4] These experiments have employed biodegradation in beds packed with soil to oxidize organic solutes in waste liquors. Laboratory and pilot-scale bioreactor columns have been used; at both scales, vacuum has been applied at the base of vertical columns to balance capillary forces and mimic so-called "field status". The goal of these experiments is to develop design criteria for in situ microbial treatment immediately in or adjacent to an uncontrolled dump or spill site.

The approach allows natural selection to control the microbial community as completely as possible. External control is achieved through management of independent parameters such as soil type, depth to groundwater, loading rates, nutrient additions, etc. A mixed microbial population is established in the soil structure. The indigenous microflora of the soil is supplemented through addition, at the soil surface, of an inoculum of a mixed microbial population derived from the secondary sludge of a municipal sewage treatment facility.

The microbial seed propagates through the soil column and permeates the soil structure. Leachate feed is added at the soil surface and is allowed to diffuse through the soil, where it is subsequently adsorbed and/or degraded through aerobic and anaerobic processes.

An experimental field apparatus was designed to examine this treatment process, (1) on a scale suitable for process design, (2) under natural environmental conditions and (3) over a prolonged period of time. To fulfill these goals, a pilot-scale treatment system was installed. The installation consists of six soil columns, termed self-contained lysimeters (SCLs), 60 cm in diameter and 120 cm deep. The SCLs were designed for complete effluent recovery, implanted in the ground and operated in simulation of field conditions. Data for bioreactor modeling was obtained from Experiment 0682, started in June, 1982 and lasting 161 days.

Numerous laboratory columns have been operated in sterile and mixed microbial modes, also. The sterile mode employs chloride ion as the market species and no nutrients. It is intended to examine residence time distributions based only on physical properties and hydraulic behavior. One of the goals of the overall research activity is the correlation of performance data for different soils and varying reactor diameters to define generalized design criteria. For this reason, various laboratory packed bed studies have been run in parallel with the pilot plant experiments.

The packed bed bioreactor is a complex system that operates with convective and dispersive flow contributions, physical adsorption and chemisorption, catalyzed non-biochemical reactions and aerobic and anaerobic mixed microbial reactor domains. With the diversity of hydraulic, physical and chemical influences, the development of performance correlations and generalized design criteria is very complex. Fully deterministic modeling is not possible. Thus, a step-by-step approach using incomplete models, as appropriate to limit state operations, was chosen. Ultimately, it is planned to couple these models in a comprehensive design scheme.

Brief discussion of two limit cases follows. The first case is that of dispersion with biochemical reaction. At some point after startup, adsorptive capacities are saturated and output responses to input variations are primarily functions of empty bed flow rate, dispersion and biochemical reaction. If the latter is taken as first-order, a simple model results. This assumption is reasonable for a mixed microbial system with many metabolic pathways. This case is termed the end-state or semi-steady-state case.

A second model has been associated with initial processes, i.e., startup. In this initial unsteady condition, biochemical reaction is minimal and the packed bed reactor is viewed as an adsorber column. Macro-diffusivities from the first case can be applied in the second case. This permits description of adsorption/desorption effects during the early stages of column operation.

DISPERSION MODEL

A dispersion model in which macro-diffusion is superimposed on plug-flow can be used to describe some reactor systems. This model is frequently employed for flow through packed beds and is an appropriate approach to bioreactive packed soil columns:

$$\frac{\partial c}{\partial t} = \nabla \cdot (E \nabla c) - \bar{u} \cdot \nabla c + \phi(c) \tag{1}$$

where $\bar{u}$ is the average fluid field velocity and $\phi(c)$ is a reaction rate and/or source term. For an isothermal, incompressible fluid at a constant flow rate in a cylindrical vessel, Equation 1 can be written:

$$\frac{\partial c}{\partial t} = E_z \left(\frac{\partial^2 c}{\partial z^2}\right) + E_r \left(\frac{\partial^2 c}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial c}{\partial r}\right) - \bar{u} \cdot \frac{\partial c}{\partial z} + \phi(c) \tag{2}$$

where E_z and E_r are the axial and radial dispersion coefficients, respectively. Both are assumed independent of concentration and position. For plug-flow with negligible radial dispersion, Equation 2 reduces to:

$$\frac{\partial c}{\partial t} = E_z \left(\frac{\partial^2 c}{\partial z^2}\right) - \bar{u} \cdot \frac{\partial c}{\partial z} + r \tag{3}$$

where r is the rate of reaction.

This model is called the "longitudinal-dispersion plug-flow model" or, sometimes, simply the "dispersion model". Langmuir[5] discussed this model and obtained the steady-state solution, using the following boundary conditions:

$$\left(\frac{\partial c}{\partial t}\right)_{z=L} = 0 \tag{4}$$

$$\bar{u}c_{z\to0} = \bar{u}c_{z\to0^+} = E_z\left(\frac{\partial c}{\partial z}\right)_{z\to0^+} \tag{5}$$

For a pulse input, Equations 3 through 5 reduce to

$$c(t) = 1000\left(\frac{M}{2A\sqrt{\pi E_z t}}\right)\exp\left(\frac{-(z-\bar{u}t)^2}{4E_z t} - kt\right) \tag{6}$$

The effective flow area and average fluid velocity are obtained from calculated mean residence time and soil porosity, i.e.,

$$\epsilon = \frac{Q}{V} \times \theta$$

$$A = A_{xs} \times \epsilon \tag{7}$$

$$\tag{8}$$

$$\bar{u} = \frac{Q}{A} \times \left(\frac{1000}{24}\right) \tag{9}$$

Before proceeding with estimates for E_z and k (rate constant), mean residence times must be derived. For this purpose, statistical methods were employed.

Statistsical comparisons of influent and effluent organic carbon concentrations were used to obtain values of mean residence time for use in Equations 7 through 9. The method employed was the F-test in a one-way analysis of variance (ANOVA) for two populations, each representing one level of treatment (influent and effluent).

Columns 1 and 2 from field experiment 0682 were examined in this study. The influent and effluent organic carbon concentrations for SCL 1 are shown in Figure 1. It was assumed that initial effluent peaks were a result of leachate adsorption coupled with microbial adaptation. For this reason, effluent data from days 1 to 75 were not used. Also, it was concluded that effluent peaks from day 75 on were a result of the influent peak between days 57 and 67.

F-tests were conducted over a range from 20 to 60 days in lagtime, with influent data from days 39 to 120. Actual F-testing was conducted with data produced from 6-day central-moving-averages. All influent and effluent data were reduced by 3 days at each end. Therefore, the normalized effluent data go only to day 158.

The influent and effluent organic carbon concentrations for SCL 2 are shown in Figure 2. Again, the effluent data from days 1 to 75 were deleted and testing was confined to the remaining effluent data and was assumed to be in response to the influent peaks between days 57 and 67. F-tests were conducted for lag times between 20 and 60 days with influent data from days 43 to 109. All points were normalized and developed from 6-day central-moving-averages.

F-distributions as functions of lagtime are shown in Figures 3 and 4. The curve for SCL 1 peaks at a lag of 39 days. This signifies that 39 days are required before an influent perturbation is "seen" in the effluent stream. In other terms, particles of mass spend an average of 39 days in the column. Similarly, Figure 4 for SCL 2 shows a single peak, at day 50. Column dimensions and calculated values according to Equations 7 through 9 are given in Table 1.

Using calculated values for porosity, average fluid velocity and effective flow area, a first approximation for E_z can be calculated. In Equation 6, k was first assumed equal to zero. Figures 5 and 6 describe predicted concentrations versus time for SCLs 1 and 2 in addition to actual effluent concentration data. A value of E_z equal to 0.3 cm²/hr appeared to be a reasonable first guess for both columns.

At this point, estimation of the rate constant (k) was possible. Returning to Equation 6, k was allowed to vary while E_z remained
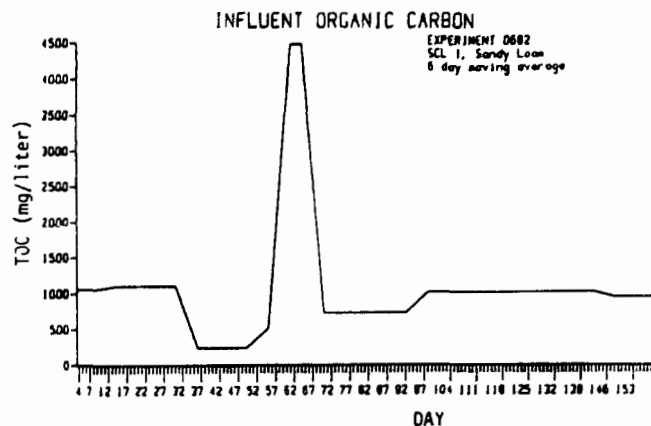
Figure 1a
Influent Organic Carbon
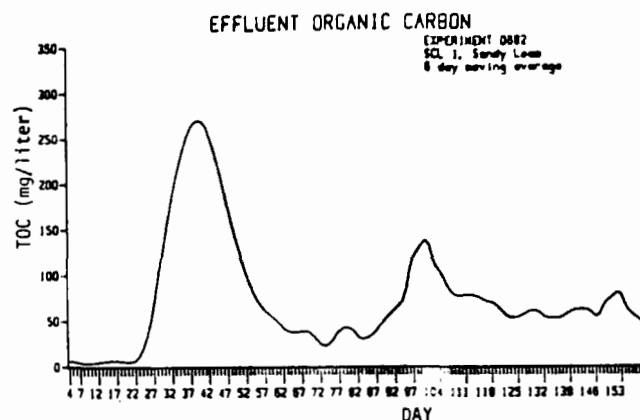
Figure 1b
Effluent Organic Carbon

Table 1
Pilot Packed Bed Properties & Performance

	SCL 1	SCL 2
Length, cm	109.2	101.6
Cross-section area, cm²	2858	2858
Volume, l	312.2	290.4
Porosity, %	40.6	40.6
Effective flow area, cm²	1160	1160
Mean residence time, days	39	50
Ave. volumetric throughput, l/day	3.25	2.36
Ave. velocity, cm/hr	0.117	0.085
Axial Dispersion coefficient, cm²/hr	0.187	0.116
Ave. rate constant	0.00351	0.00188

fixed at 0.3 cm²/hr. It was found that k alters both the magnitude and location, or skew, of the peak. For a first approximation, magnitude was deemed most important. Thus, a value for k equal to 0.0075 hr⁻ was obtained for SCL 1. Similarly, k was approximately 0.0015 hr⁻¹ for SCL 2. Optimum values of E_z and k are summarized in Table 1. In Figures 7 and 8, predicted data are compared to observed data; agreement is good. Final values of E_z and k were based on simultaneous regression of both E_z and k over narrower ranges of values to minimum values of the objective function.
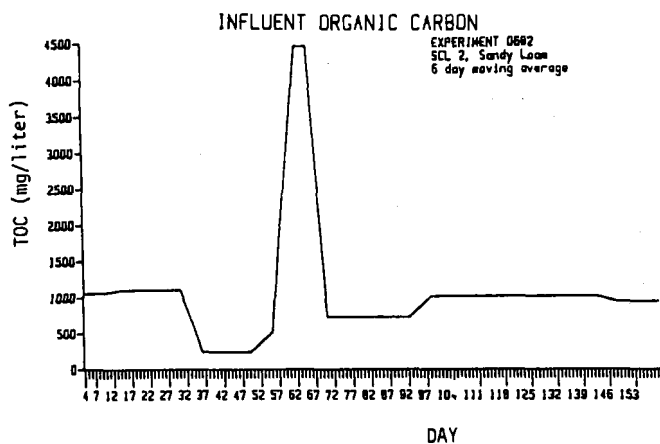
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Influent Organic Carbon
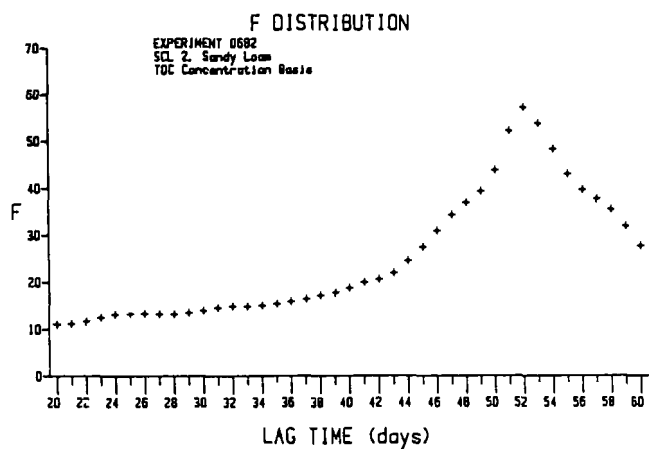
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F Distribution, SCL 2
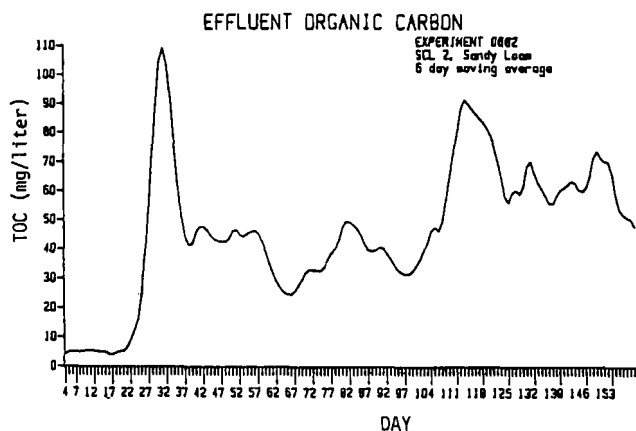
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Effluent Organic Carbon
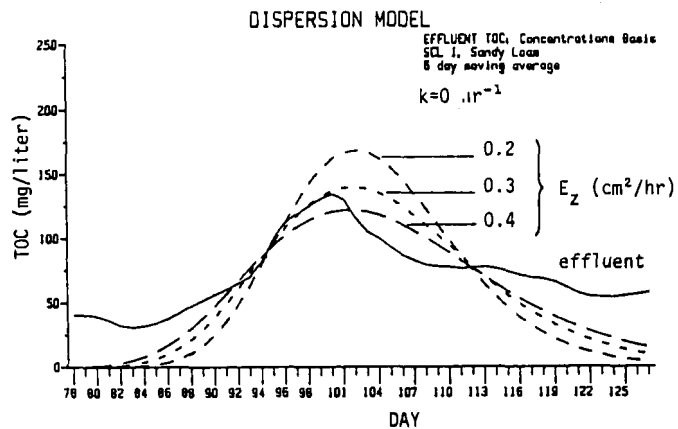
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Dispersion Model, SCL 1
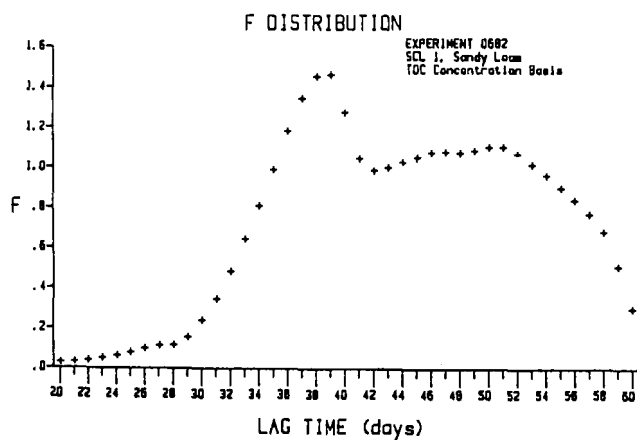
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F Distribution, SCL 1
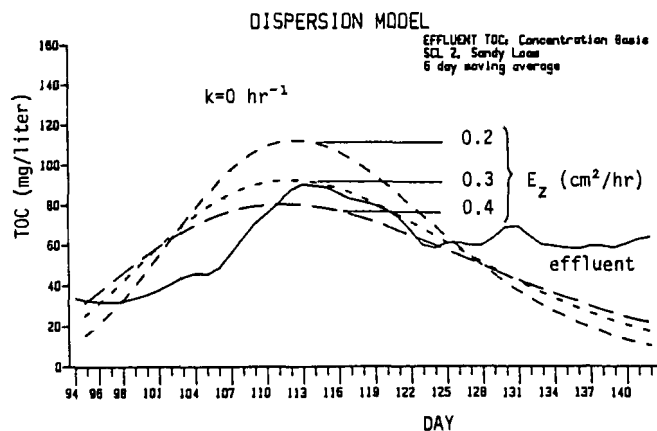
Figure 6
Dispersion Model, SCL 2

ADSORPTION/DESORPTION EFFECTS

If r is replaced by $\propto$, an expression for the relative rate of adsorption/desorption, Equation 3 is relevant to a pure unsteady-state adsorption column. This is the situation during treatment column startup; biochemical reaction is minimal because of the low density of microbial populations. Physical and non-biochemical surface binding dominate.

Let α be given by:

$$\alpha \quad \frac{\rho}{\eta} \cdot \frac{\partial q}{\partial t} \tag{10}$$

where ρ is solid phase density, η is soil moisture content at saturation and q is concentration of solutes on solid surfaces (as mass/mass). Further, assume simple partitioning of solutes

$$q \quad k'c \tag{11}$$

In the absence of biochemical reaction, Equation 3 becomes

$$\frac{\partial c}{\partial t} \quad E_z(\frac{\partial^2 c}{\partial z^2}) \quad \bar{u}(\frac{\partial c}{\partial z}) \quad \frac{\rho k'}{\eta}(\frac{\partial c}{\partial t}) \tag{12}$$

or

$$R_c(\frac{\partial c}{\partial t}) \quad - \quad E_z(\frac{\partial^2 c}{\partial z^2}) \quad \bar{u}(\frac{\partial c}{\partial z}) \tag{13}$$

where

$$R_c \quad \frac{\rho k'}{\eta} + 1 \tag{14}$$

is a retardation factor. The boundary conditions of Equations 4 and 5 are appropriate. The desired "initial" condition is a step, not a pulse, in this case, i.e.,

$$c \quad 0 \text{ at all } x \text{ and } t = 0^- \tag{15}$$

$$c \quad c_0 \text{ at } x \leqslant 0 \text{ and } t \geqslant 0$$
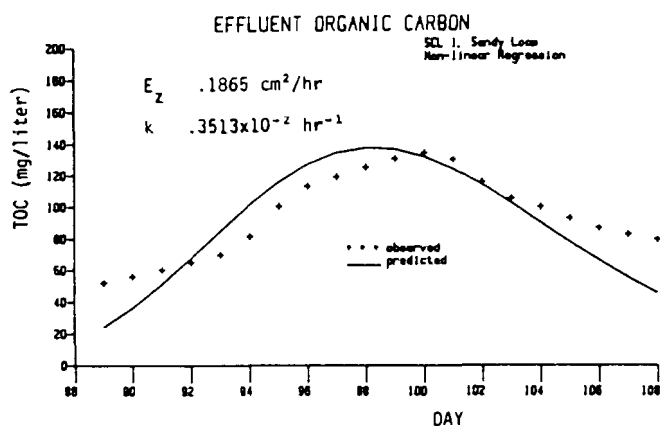
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Effluent Organic Carbon, SCL 1
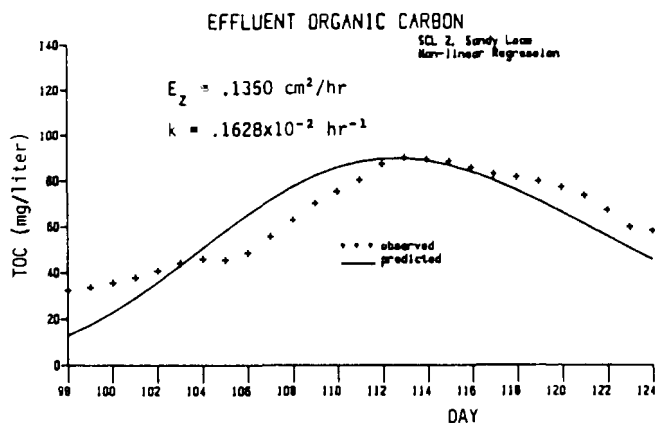
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Effluent Organic Carbon, SCL 2
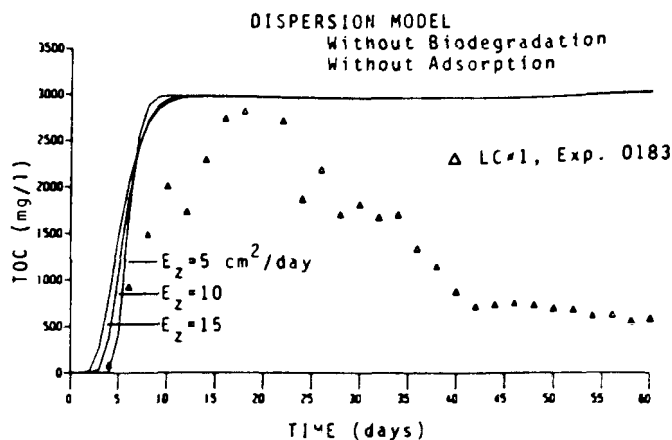
Figure 9
Dispersion Model — Without Biodegradation; Without Adsorption
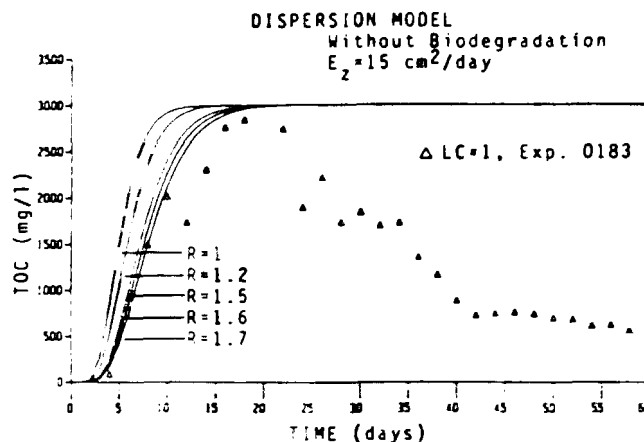
Figure 10
Dispersion Model — Without Biodegradation; E_z = 15 cm²/day

Equations 13 and 15 were solved with numerical methodology, i.e., the "classic explicit" finite difference methodology described by Lapidus and Pinder.[4] Effluent concentrations were averaged over one day intervals to mimic experimental sampling conditions.

Sensitivity of the equations to variations in E_z and R_c is illustrated in Figures 9 through 11. In these plot, the numerical solution is compared to experimental data obtained from a laboratory column (LC) during Experiment 0183. It can be seen that the solution of Equations 13 and 15 is considerably more sensitive to changes in R_c than to changes in E_z. The best fit of experimental data from LC 1 was obtained for R_c equal to 1.7 and E_z equal to 15 cm²/day or about 0.63 cm²/hr.

It was assumed that similar hydraulic and adsorptive conditions prevailed for LCs 2 through 4, during Experiment 0183. These columns were packed with the same soil and operated in like fashion but received feed solutions of varying concentrations. The influent TOCs for LCS 1, 2, 3 and 4 during the experiment were 3000, 2000, 1000 and 210 mgC/l, respectively. The results for the numerical solution for these cases, assuming R equal to 1.7 and an E_z of 15 cm²/day, are presented in Figure 12. Experimental data are included, also. The E_z estimated for the laboratory columns compares favorably with the dispersion coefficients obtained from field data. They vary by less than a factor of five, i.e., order-of-magnitude the same for such soil properties.

The model based on dispersion and adsorption is a reasonable approximation of the processes that occur initially during startup of the bioreactor columns (Fig. 12). This is an expected response to the relatively small microbial populations present at the beginning of an experiment. As a bioslime develops, removal of organic car-
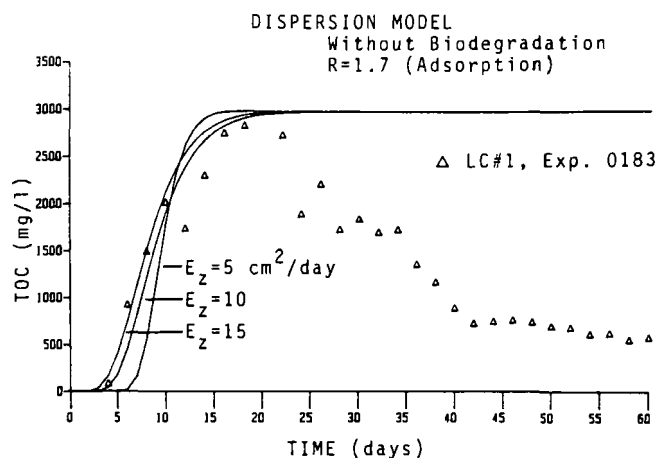
Figure 11
Dispersion Model — Without Biodegradation; R = 1.7 (Adsorption)
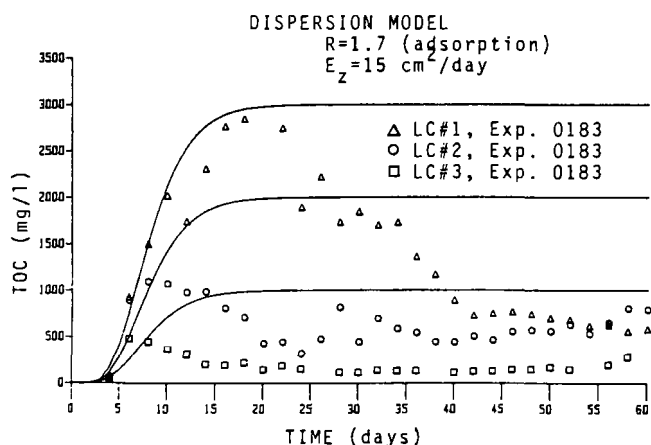
Figure 12
Dispersion Model — R = 1.7 (Adsorption); E_z = 15 cm²/day

bon by biodegradation becomes increasingly important. The difference between predicted and actual TOCs becomes significant after 20, 10 and 7 days, respectively, for LCs 1, 2 and 3.

With decreasing influent TOCs, biodegradation becomes the controlling process more rapidly. This result is most likely because a larger fraction of the influent TOC is in the form of glucose for the lower overall TOC levels. Thus, the organic carbon in the feed streams to LCs 2 and 3 was more readily assimilated than that fed to LC 1, and the acclimation period was shorter.

CONCLUSIONS

A multi-faceted approach has been used for parameter estimation and modeling of the complex, interacting processes occurring in a soil-based, bioreactor system. Steady-state was assumed for microbial and adsorptive processes after a prolonged period of operation. This assumption permitted the application of a modified statistical test to determine packed bed porosities and mean residence times for two pilot-scale columns. In turn, this information was used in a dispersion model incorporating first-order reac-

tion kinetics. Dispersion coefficients and pseudo-first-order rate constants were calculated for field experiments.

Laboratory-scale columns were used to study the competition between physical and chemical processes during reactor column startup. A dispersion model with first-order reversible adsorption kinetics has been shown to be useful for the analysis of column performance before a significant bioslime develops. Modeling for the transition regime between the two limit cases is in progress.

Step-by-step simplified modeling has been found to be a reasonable initial step to the development of design criteria, scaling factors and loading estimation for in situ leachate and spill liquor treatment.

NOMENCLATURE

A	effective flow area, cm²
A_{xs}	column cross-section area, cm²
c	concentration, mg/liter
E_r	radial dispersion coefficient, cm²/hr
E_z	axial dispersion coefficient, cm²/hr
k	first-order reaction rate constant, hr^{-1}
k^1	partition coefficient, l/mg
M	mass of pulse input, mg
Q	ave. volumetric throughput, l/day
r	reaction rate, mg/l, hr
R_c	retardation factor, dimensionless
t	time, hr
$\bar{u}$	ave. velocity, cm/hr
V	volumetric capacity, l
z	axial position $(0 \leq z \leq L)$, cm
α	adsorption/desorption rate, mg/l, hr
ϵ	porosity, dimensionless
η	moisture content at saturation, dimensionless
ρ	solid phase density, mg/l
θ	mean residence time, hr

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THE USE OF A MICRODISPERSION OF AIR IN WATER FOR IN SITU TREATMENT OF HAZARDOUS ORGANICS

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INTRODUCTION

In this paper, the authors describe the use of a microdispersion of air in water for treating hazardous organics. In particular, the air microdispersion generated and tested in this study was a 60 to 65% mixture of air bubbles, 25 to 50 μ in diameter and water, often referred to as Colloidal Gas Aphrons (CGAs).

In these microdispersions, air bubbles are encapsulated in thin "soap" films that are so tenacious that the bubbles do not coalesce, even when pressed together. Hence, the bubbles remain very small (on the order of 25 μ) and present an enormous surface area. One litre of CGA containing 60% of gas as 24 μ diameter bubbles contains 8.3×10^{10} bubbles with a surface area of 150 m^2, about 1/6 the area of an olympic swimming pool. These air dispersions or CGAs can be generated using virtually any water soluble surfactant with concentrations as low as 100 mg/l and any gas of limited solubility (e.g., nitrogen, oxygen, carbon dioxide). With selected surfactants, dispersions can be generated containing 65% gas by volume. CGAs must be clearly distinguished from the so-called "bubbles" produced by dissolved air precipitation, sparging or electrolysis, all of which are 2 to 1000 times larger and rise to the surface rapidly where they quickly coalesce. Recent papers by Auten and Sebba[1] and Sebba,[2,3] provide a good background on the characteristics of CGAs.

Because these fine microdispersions are so stable and small, they can remain suspended in solution and can flow through channels such as exist in a sand bed. Larger, unstable "bubbles" are filtered out in such a situation. Another important characteristic is that CGAs can be pumped with many positive displacement pumps without deterioration.

A description of CGA production has been given by Sebba and Barnett.[4] "CGAs can be made very simply by passing a very rapid stream of dilute (about 2×10^{-3}M) surfactant solution through a venturi throat, at which point there is a very restricted orifice through which gas (usually air) under an excess pressure of about 1 atm is sucked into the stream. Because of the turbulent jet and the slow entry of gas, it enters in the form of microbubbles. A requirement for the generation of a shell encapsulated bubble is that the gas break through an aqueous-gas surface, with a surfactant monolayer at the surface, at least twice. The turbulence ensures that. In contrast, if a so-called "bubble" is introduced by sparging through a fitted disc or by gas precipitation, this is likely to be gas surrounded by the bulk water and have only one interface, and therefore, is effectively a gas-filled hole. To obtain a high concentration of CGA bubbles, the suspension is recycled a few times through the CGA generator. The method described for generating CGAs is excellent for laboratory production, and a generator of this type can operate for many years."

In the laboratory, CGAs have since been generated using a spinning disk in a baffled chamber. The production of CGAs can also be achieved using a high speed commercial blender. These procedures have been scaled-up with effective production in a 19 l stainless steel continuous (stirred) tank. More recently, Keane[5] has patented several processes for producing 10 to 25 μ direct nucleate flotation DNF bubbles which should have similar characteristics to CGAs, although it is doubtful whether 10 μ sized bubbles can have more than a transient existence.

The applications of Colloidal Gas Aphrons (CGAs) have, to date, been focused on the removal of very fine suspended or precipitated particles. The mechanism of separation can range from a combination of ion flotation and precipitation flotation to floc flotation, according to Sebba and Barnett.[4] Barnett and Liu[6] floated hydrophilic colloidal particles such as found in fish wastes from aqua-culture systems. Sebba and Yoon[7] demonstrated that CGAs were able to selectively float coal wetted with kerosene from ash.

Auten and Sebba[1] have shown that it is possible to separate minerals by selective bubble entrained floc-flotation. They explored the ability of fine CGA bubbles to be entrained in the flocculated clay from the phosphate slime effluent and in this way to separate these very finely divided particles from apatite. In another application, CGAs were shown to be effective in the flotation-harvesting of single cell algae from a dilute suspension.[8]

For many separations, it is the distinctive characteristics of the air dispersions which make the applications technically feasible. Sebba and Barnett[4] have discussed the use of CGAs for a wide range of liquid/liquid and liquid/solid separations.

In Situ Hazardous Waste Treatment

The treatment of subsurface hazardous waste releases to soil matrices or to impoundment sediments is limited to: (1) injection/recovery techniques with above ground treatment, or (2) subsurface in situ treatment (destruction) techniques. This assumes, of course, that the releases exceed the depth appropriate for land treatment and that excavation followed by biodegradation, destruction, encapsulation and/or disposal in a hazardous landfill is not practical, economical or safe.

In the field, the use of injection/recovery techniques has become accepted practice. For example, according to a USEPA survey completed by Neeley et al.[9] of 180 remedial actions (on 169 sites), recovery wells and French drains (with and without surface treatment) were used in 15 situations to prevent groundwater contamination from landfills. On the other hand, only two instances were noted in which in situ treatment was used, and in each of these applications, the actual groundwater treatment was carried out above ground.

In a recent update of the remedial action survey, USEPA[10] has reported that O.H. Materials and the State of New Jersey conducted spray irrigation with draw down wells to remove contaminants from groundwater at the Goose Creek site in Plumstead Township. The actual water treatment, again, was completed above ground.

The use of stripping techniques has become quite common for removing light chlorinated compounds such as TCE and PCE from contaminated groundwater. For example, Gross and Termaath[11] recently reported a study for the U.S. Air Force at Wurtsmith Air Force Base treating 6600 m³/day. The process included the use of activated carbon processing for the final treatment following packed tower aeration. Cummins[12] of the USEPA has been conducting and monitoring tests at several sites to determine the effectiveness of air stripping for removing contaminants.

A survey of the contaminants found at the 114 top priority Superfund sites has been completed.[13] At these sites, 64 incidences were noted where slightly soluble organics, including aromatics and halogenated hydrocarbons occurred. Most of these would be amenable to injection/recovery techniques, but some organics would be biodegradable if subsurface in situ biooxidation techniques were developed and accepted as "state-of-the-art."

Occasionally, surface spills of hazardous waste have been treated in place. Harsh[14] documented the in situ neutralization of acrylonitrile by first raising the pH of the area above 10 with lime and then spraying sodium hypochlorite over the area. Winn and Schulte[15] reported the cleanup of 6400 kg of phenol by treating a total of 3800 m³ of diluted waste with hydrogen peroxide. Other recent papers by Sikes, et al.[16] and Miller and Paddock[17] document in situ treatment of formaldehyde and acetic anhydride spills respectively. Zitrides[18] from Polybac Corporation has provided a bibliography of a number of spill situations at which full-scale applications of selected mutant microorganisms, as well as mixed microorganisms from waste treatment plants, have been used for biodegradation of surface spills. A more recent paper by Kretschek and Krupka[19] updates the methods and work by Polybac to further develop the state of the art. Again these citations emphasize above ground treatment.

Enhanced Injection/Recovery Techniques

A limited number of studies are continuing to enhance the efficiency of injection/recovery techniques using surfactant solubilizing agents. Given a choice, injection/recovery procedures followed by above ground treatment are usually preferred to below ground in situ treatment.

Texas Research Institute,[20,21] conducted several laboratory, column and two dimensional modeling tests on the use of surfactants to enhance gasoline recovery from high permeability sand. These results indicated that, with a surfactant combination of an anionic (Richonate-YLA) oil soluble surfactant and a nonionic (Hyonic PR-90) surfactant, effective recovery was achieved. These results suggested that enhanced injection/recovery techniques may be limited to recovery of slightly soluble organics released to high permeability subsoils. The recovery efficiency also dropped off as testing went from one dimensional plug flow tests to three dimensional large sand box tests. More recently, Ellis, et al.[22] completed laboratory work which has demonstrated overall soil cleanup efficiency of 90% under gravity flow conditions of intermediate molecular weight aliphatic and aromatic hydrocarbons, polychlorinated biphenyl mixtures and chlorinated phenol mixtures. A combination of 2% each Hyonic PE 90 and Adsee 799, both nonionic surfactants, were used for testing. Further testing is in progress.

Subsurface In Situ Hazardous Waste Treatment

Above ground treatment is generally desirable if the contaminant can be removed from the soil or sediment matrix by injection/recovery techniques, forced venting or evaporation techniques. The complete excavation of the site or impoundment sediment followed by thermal, chemical or biological oxidation treatment, encapsula-tion, or disposal in a hazardous waste site are also possibilities, although usually expensive. The final available option is to treat the buried hazardous waste in place by some chemical, biological or thermal destruction technique or physical isolation.

The treatment of gasoline contaminated groundwater and soil matrices using biological techniques has received the most attention. Recent articles by Lee and Ward[23] and Yaniga[24] survey the work completed. Recently, the American Petroleum Institute (API) has also initiated a field study on the use of hydrogen peroxide to transport oxygen subsurface for gasoline degradation.[25] In addition, the authors have been testing the use of Colloidal Gas Aphrons as an oxygen source for subsurface biodegradation under API sponsorship at Virginia Tech.

One of the few documented field efforts to conduct subsurface in situ biodegradation of hazardous organics is being completed by Biocraft Laboratories at its Waldwick, New Jersey site by its subsidiary, Groundwater Decontamination Systems (GDS). The technology developed has been patented and GDS was formed to sell the biostimulation process to other firms with similar groundwater problems. Their processing consists of two delivery trenches (1.5 m × 30 m × 3 m), upgradient of a contamination source, with a subsurface drain trench (1.5 m × 3 m × 24 m) for primary collection located down gradient. Their innovation comes in the injection of air at several points into a 3.5 m thick contaminated layer of glacial till and stratified drift located 1 m underground. According to an earlier soil summary, three basic soil types occurred in the area: (1) Merrimac gravelly loam, (2) Papakating silt loam, and (3) muck. In addition to some in situ (subsurface) biodegradation, above ground biological degradation of the contaminated groundwater was also conducted before it was recycled back into the reinjection trenches. Nutrient levels and microorganism populations were closely controlled. The subsurface horizontal flow rate was estimated to be 0.12 m/day, and it takes an estimated year and a half for reinjected water to traverse from delivery to drain trench. Permeabilities (hydraulic conductivities) have been estimated to be 9.4×10^{-9} to 1.7×10^{-5} m/s from slug tests.[26]

Finally, laboratory studies have been completed on the use of radio frequency in situ heating for decontamination of hazardous waste substance[27] and degradation of high concentrations of diazinon in soil by parathion hydrolase.[28] Whether either of these treatments would be suitable for deeper subsurface waste is unclear.

In summary, subsurface in situ biodegradation of organics seems feasible, but efforts to date have emphasized gasoline degradation. In addition, no effort has been identified to enhance in situ biodegradation of impoundment sediments.

RESULTS AND DISCUSSION

Earlier small scale laboratory studies have demonstrated that colloidal gas aphrons, when sparged into various unconsolidated saturated soil matrices, are "picked up" and retained for a prolonged period of time.[29] During these tests, 70 to 82% of the air incorporated into a CGA made using a nonionic detergent (Tergitol 15-S-12) immediately adhered to a saturated coarse sand after sparging with a fork-like probe. Thirty days later, 70 to 80% of the initially retained CGAs were still retained in the saturated sand matrix as an air dispersion or as coalesced aphrons. On injection, some expansion of the saturated sand bed occurred and the range of air to water, by volume, in the saturated sand was 0.56 to 1.25. With CGAs made using sodium dodecyl benzene sulfonate, a maximum of 63% of the CGAs adhered to the coarse sand with about 60 to 70% of these retained after 30 days. On the other hand, direct air injected following the same procedures rapidly "bubbled up" and burst through to the surface with little air retention.

In situ laboratory biodegradation studies also demonstrated that a combination of CGAs and *Pseudomonas putida* plus microbial nutrients could be injected into a saturated anaerobic sand matrix containing 300 mg/l phenol solution, and 60% of the phenol was degraded in 24 hr.[29]
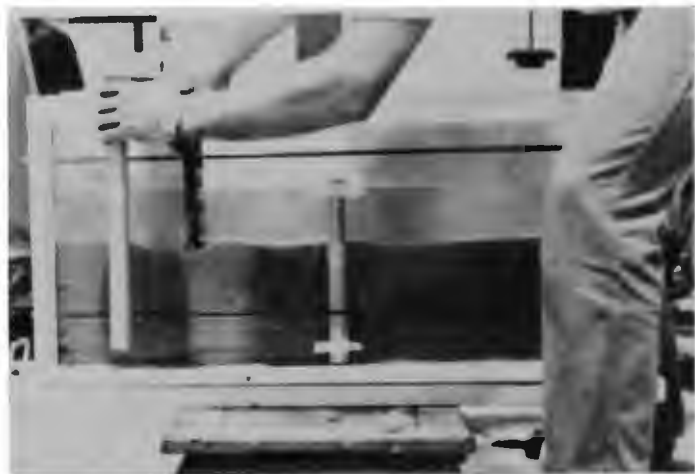
Figure 1
CGA Injection: Pilot Trough Test (Underway)

Figure 3
Injector Delivery Hardware

Figure 2
CGA Injection: Pilot Trough Test (Midway)

Figure 4
Injector Details of Plow and CGA Holes

Air Retention in Pilot Trough Tests

Because of these encouraging laboratory retention studies, scale-up adhesion tests were conducted in a 13 cm wide trough, 91 cm long by 46 cm high with one side made of clear polycarbonate (Figs. 1 and 2). The side view panel made it possible to follow injection when plowing adjacent to the near wall. The air colloidal gas aphrons were generated and introduced below the saturated sand surface (impoundment bottom). The injector was made from 0.6 cm steel pipe with two 0.3 cm diameter holes located just upwards from the plow point (Figs. 3 and 4). Injection was made by bracing the side supports to maintain the delivery plow vertical. The percent CGA (gas) retention could be determined by knowing the amount of surfactant solution injected as CGAs, the quality of the CGAs (percent composition air, determined by withdrawing 100 ml into a graduate cylinder and allowing slow coalescence to a liquid) and the water surface level change in the trough after CGA injection. Percent "Air Retained" is the volume air retained per the volume air injected (as CGAs).

The results of these injection studies into Ottawa Federal Fine silica sand are shown in Table 1. All runs were made with injection of CGAs about 10 cm below the sand surface, such that the plow tip was about 13 cm deep (Fig. 3). The "Surfactant" column lists the surfactant, concentration and CGA quality. The plow position was moved to inject at three positions along the 13 cm width.

The "Total Air Input" was determined by measuring the surfactant liquid solution delivered and CGA quality. The volume "Air Retained" was determined by the measured total volume change less the total liquid volume added as CGA dispersion. The "% Void Volume Filled" was approximated based on a previously measured void volume, porosity of 0.40 for the saturated Federal Fine sand and ignoring any expansion of the bed during CGA addition. Only the top 10 cm of the saturated sand were considered in these calculations.

These results show that the faster plow rate and the slower CGA delivery (flow) rate both contribute to enhanced percent air retention. The maximum retention of about 50% may seem low, but the crude injector design did not deliver a fine stream of CGAs through the 0.30 cm holes, and this left considerable opportunity for CGAs to accumulate and channel up the back of the vertical plow shaft. With similar surfactant concentrations, CGA retentions of well above 50% were achieved in laboratory tests in a two-inch deep sand bed using a pronged "fork" injector made of 0.16 cm diameter tubing. In addition, 56% void volumes filled with air was achieved in these laboratory tests, again assuming no bed expansion. The three-prong fork (rake) moved through the sand with minimal sand disruption as large gaps, thus assuring better CGA contacting with the sand and thus better retention.

In summary, large quantities of air (or oxygen) as CGAs can be injected and retained in an unconsolidated saturated sand matrix (impoundment) under pilot trough testing. However, better plow/injector design and fabrication should be undertaken at the field scale to maximize the retention achieved at the laboratory level.

Table 1
Results of Adhesion and Retention of Colloidal Gas Aphrons in Saturated Sand Matrix - Sand Trough Tests

Run No.	Surfactant	CGA Flow Rate (Water Plus Bubbles)	Flow Rate	Number of Total Passes	Total Air Input	Air Retained Vol.	%	% Void Vol. Filled	Avg. Air Input Per Pass
1	Tergitol 15-S-12 0.3 g/l (59% CGA) Avg	750 ml/min	Medium 30 sec/pass	30 (10/position) 30 (10/position) 60 Total	1758 ml 1895 ml 3653 ml	660 ml 423 ml 1083 ml	38% 22% 30%	14% 24% (total) 24%	59 ml 63 ml
2	NaDBS (0.3 g/l) (57% CGA)	750 ml/min	Medium 30 sec/pass	30 (10/pos.) 30 (10/pos.) 60 Total	1640 ml 1694 ml 3334 ml	554 ml 468 ml 1022 ml	34% 28% 31%	12% 22% (total) 22%	55 ml 56 ml
3	NaDBS 0.3 g/l (58% CGA)	750 ml/min	Slow 75 sec/pass	20 (10/wall pos.) 10 (center) 30 Total	4350 ml 2956 ml 7306 ml	1015 ml 175 ml 1190 ml	23% 6% 16%	22% 26% (total) 26%	218 ml 296 ml
4	NaDBS (60% CGA)	750 ml/min	Slow 75 sec/pass	12 (4/pos.) 12 (4/pos.) 24 Total	2847 ml 3072 ml 5919 ml	329 ml 417 ml 746 ml	12% 14% 13%	7% 16% (total) 16%	237 ml 256 ml
5	NaDBS (59% CGA)	500 ml/min	Medium 31 sec/pass	30 (10/pos.) 30 (10/pos.) 60 Total	1701 ml 1436 ml 2737 ml	723 ml 433 ml 1156	43% 29% 42%	16% 25% (total) 25%	57 ml 48 ml
6	NaDBS (59% CGA)	500 ml/min	Slow 75 sec/pass	20 (10/wall) 10 (center) 30 Total	2888 ml 1168 ml 4056 ml	782 ml 293 ml 975 ml	27% 25% 24%	17% 21% (total) 21%	144 ml 117 ml
7	NaDBS (57% CGA)	500 ml/min	Slow 75 sec/pass	12 (4/pos.) 12 (4/pos.) 24 Total	1396 ml 1644 ml 3040 ml	667 ml 590 ml 1257 ml	48% 36% 41%	15% 27% (total) 27%	116 ml 137 ml
8	NaDBS (63% CGA)	250 ml/min	Medium 31 sec/pass	30 (10/pos.) 30 (10/pos.) 60 Total	1581 ml 804 ml 2385 ml	941 ml 238 ml 1179 ml	59% 30% 49%	20% 26% (total) 26%	53 ml 27 ml
9	NaDBS (62% CGA)	250 ml/min	Medium 30 sec/pass	30 (10/pos.) 30 (10/pos.) 60 Total	1013 ml 969 ml 1952 ml	529 ml 426 ml 955 ml	52% 44% 48%	12% 21% (total) 21%	34 ml 32 ml
10	NaDBS (57% CGA)	250 ml/min	Slow 75 sec/pass	30 (10/pos.) 30 (10/pos.) 60 Total	2246 ml 2280 ml 4525 ml	1031 ml 480 ml 1511 ml	46% 21% 33%	22% 33% (total) 33%	75 ml 76 ml

Laboratory Phenol Degradation Studies with CGAs

To verify early reported results and establish analytical procedures, a phenol degradation study in a saturated sand matrix using CGAs was completed. To a series of 250 ml beakers, 310 g of Ottawa Federal Fine sand were added. Then 300 mg/l phenol solution was added until just covering the sand bed (one pore volume). Then a 0.3 g/l solution of sodium dodecyl benzene sulfonate was blended into a 33% CGA (poor quality) and 78 ml of liquid pumped in as CGA. This resulted in an average of 18 cm^3 of air as CGA retained in the saturated sand matrix, approximately 23% of the pore volume. The CGAs were injected using a 1.0 ml pipe with vigorous stirring. The phenol concentration in 12 individual samples was followed and phenol degradation as a function of time is shown in Table 2. The sacrificed sample was well mixed before analysis.

The results verified that after approximately 24 hr degradation was complete, which is in agreement with earlier tests.[29] A similar set of runs was made using 60% quality CGAs, which showed that 95% of the phenol was degraded by 45 hours. Thus, a test period of 24 hr was considered as appropriate for further testing.

Phenol Degradation-CGAs Dispersion/Diffusion

Both laboratory and trough tests have demonstrated the ability of air (or oxygen) as CGAs to be injected in sizeable volumes into saturated matrices. However, there was concern as to how much oxygen dispersion occurred during injection as well as how much diffusion took place subsequently. Since CGAs are injected as a 60 to 70% air dispersion in water or waste water, some flow and dispersion will take place from the point of injection. The CGA dispersion is also assisted by the disruption and settling of the saturated matrix or impoundment sediment during injection.

Small scale pilot dispersion studies were conducted in a 28 cm diameter, 10 cm high glass vessel. Federal sand was placed in the vessel (5 cm deep) and the sand saturated to the sand surface with a

Table 2
Degradation of a 300 mg/l Phenol Solution in a Saturated Sand Matrix as a Function of Time
(Laboratory Batch Test)

Elapsed Time (hr)	Degradation (%)	No. Samples Sacrificed
0	0 (± 10%)	2
4.8	0	2
8.2	0	2
20.5	80%	2
28.1	100%	2
47.3	100%	2

300 ppm phenol solution. CGAs containing *Pseudomonas putida* and nutrients were introduced through a 1 ml pipette injector into an 8 cm diameter center section of sand. All CGAs were made using a 0.3 g/l NaDBS solution to produce a 50% quality CGA dispersion. Caution was taken to keep the initial phenol solution anaerobic, and following CGA introduction the top of the vessel was swept with carbon dioxide and covered to eliminate oxygen diffusion to the water surface.

The results of these dispersion/diffusion studies are shown in Table 3. The initial concentration of the phenol was adjusted to reflect dilution by water introduced in the CGAs added to the 300 mg/l phenol charge solution. The final phenol solution was determined by mixing and draining the treated product from the test vessel and measuring the phenol using a colorimetric assay, based on rapid condensation of phenol with 4-aminoantipyrene, followed by oxidation with potassium ferricyanide. The gas hold-up was estimated using relatively inaccurate volume measurements, and thus the gas hold-up could be in error by ± 50 ml.

Table 3
Phenol Degradation Using Injected CGA as Oxygen Source
(24 Hour Diffusion Study)

#	CGA Gas	Est. Gas Hold-Up (ml)	Initial Vol. Liq. Added (ml) [% Gas]	Initial Phenol Conc. (Dilution mg/l Adjust.)	Final Phenol Conc.	Biode-grada-tion (%)
A	Air	98	1710 [6]	280	220	21
B	Air	198	1670 [12]	265	240	9
C	Air	205	1530 [13]	270	210	22
D	Air	121	1500 [8]	280	200	29
E	O₂	173	1470 [12]	260	200	23
F	O₂	80	1480 [5]	290	230	21

If the CGAs were effective only in the centered 8 cm diameter injection region of the 28 cm diameter vessel, the maximum phenol degradation would have been 7.4%. The results given in Table 3 indicate the effectiveness was 3 to 4 times greater. In addition, the estimated CGA hold-up gas in the injection region was equivalent to 5% to 13% of the total pore volume of the vessel, ignoring any expansion. Thus, in these tests, anywhere from about 1 to 4 volumes of saturated water containing phenol were treated for each volume of CGA air or oxygen retained in the saturated sand.

Phenol Degradation-Trough Test

The final test in this sequence was a phenol degradation study in the test trough. Specific concern centered on delivery of CGAs and biodegradation of the 300 mg/l phenol solution. The details of the test are shown in Table 4.

Table 4
Biodegradation of Phenol Using Air CGAs Plus
Microorganism and Nutrients
Pilot Trough Test

1. Total initial phenol solution to saturate 15 cm federal fine sand and provide 5 cm liquid head — 12380 ml (300 mg/l phenol)

2. Total liquid added as CGA (100 ml of a *P. putida* seed culture was added to 5.0 l of 0.3 g NaDBS/l solution for CGA generation) = 1320 ml (30 mg/l phenol)

3a. Liquid removed so as to return liquid head to original 5 cm level = 2242 ml
    } 4792 ml
    { (240 mg/l phenol)

3b. Liquid removed so as to reduce liquid heat to 0.6 to 0.9 cm = 2550 ml

4a. After 24 hr, five 10 ml samples withdrawn at different positions along the box, and all 2.5-k3.8 cm deep, and analyzed for phenol concentration (top row of concentrations shown below)

4b. Five 10 ml samples withdrawn, as above, 5 to 64 cm deep (lower row of concentrations)

5a. Upper sand bed collected, mixed, and analyzed

5b. Lower sand bed collected, mixed, and analyzed

Test Trough Schematic and Point Sample Analysis Results

Liquid Head						
6 in — Sand						T
	190	140	210	190	250 (mg/l)	Upper Sand Bed
4 in	250	180	200	190	260 (mg/l)	⊥
— Injector port level						Lower Sand Bed
2 in — Plow tip level						T
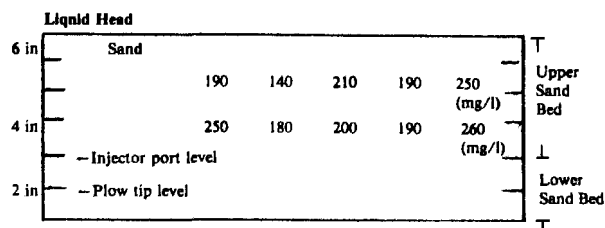
The CGAs were added at a flow of 250 ml of CGAs per minute with a slow plow rate of 75 sec per plow pass. A total of 20 passes were made at the 10 cm injection depth—10 at the middle position and 5 apiece at each side (wall) position. With a 61% quality CGA solution, 1320 × 61/39 or 2065 ml of air was injected and 922 ml retained, for a 45% retention. Given that air was distributed into the top 11 cm, then 922 ml of a total pore volume of approximately 8,000 ml was occupied (12%).

The in situ biodegradation performance is also of interest. After point concentration samples were taken (Table 4), the upper sand bed (plus liquid) was skimmed, thoroughly mixed and the water analyzed for phenol yielding a 230 mg/l average concentration. The 922 ml of retained air provided about 254 mg/l of O₂ for biodegradation @ 25°C. Furthermore, assuming that only the phenol in the upper 11 cm of sand was biodegraded, then a total of approximately 6.7 l of water were treated with a 292 to 230 mg/l reduction in phenol concentration. The total phenol biodegraded was 414 mg of phenol. Thus, 1.6 mg phenol/mg O₂ retained were degraded in 24 hr. The degradation agrees with typical yields of substrate consumed per O₂ utilized, which typically ranges from 0.5 to 3.0.[10]

CONCLUSIONS

Given that hazardous treatment is to be conducted in situ, the use of CGAs offers a unique opportunity to introduce oxygen, or perhaps ozone, to treat dissolved and possibly suspended organics found in saturated impoundment sediments. Delivery of CGAs by some injection plow looks especially promising for converting an anaerobic impoundment to an aerobic environment for enhanced biodegradation. Under such circumstances, air injection is totally ineffective.

Delivery of CGAs by a series of injection wells could also prove effective for introducing air or oxygen into saturated subsoils, into partially saturated subsoils at the water interface where floating organics will concentrate and perhaps into the capillary zone above the saturated region. The adhesion and retention of CGAs and capability to mix and deliver a complete treatment solution (air or oxygen, as CGAs, nutrients and selective microorganisms) to a particular area provides a one-step biodegradation formulation.

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THERMAL TREATMENT OF SOLVENT CONTAMINATED SOILS

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INTRODUCTION

Hazardous waste sites frequently contain large quantities of contaminated soils. The costs associated with transporting and disposing these contaminated soils to an approved landfill can be prohibitive when large volumes of soil are involved. Additionally, landfill may not provide a permanent solution to the problem; the soils may have to be handled again at some future date to effectively render them non-hazardous. Thermal treatment of contaminated soil can be a viable alternative. The following material is the method description and decision rationale for the treatment of solvent contaminated soils from an abandoned solvent reclamation facility.

BACKGROUND

The subject site for this report is one acre in size and located in a heavily industrialized area. The facility operated from 1971 to 1983; spills and discharges significantly contaminated local soil and groundwater. As a complicating factor, a drinking water well field which serves 100,000 people is located approximately 2,100 ft from the site. During 1984, the USEPA instituted a cleanup action to mitigate the threat of solvent migration into the well field.

Contaminated soil on-site is classified as brown and white sandy topsoil; groundwater is encountered between 4 to 7 ft below the soil surface throughout the site. The major contaminants found to be flowing from the topsoil to the groundwater surface were 1,1,1 trichloroethane, trichloroethene, toluene, ethyl benzene and ortho-meta- and para-xylene in concentrations ranging from 10,000 to 110,000 ppb.

RATIONALE

Two alternatives for mitigating the contaminated soil problem were found to be feasible. The first alternative would involve excavation of the contaminated soils, transportation to a secure hazardous waste landfill for disposal and backfilling of the excavated areas.

The second alternative would entail excavation of contaminated soil, transportation to a thermal treatment unit where the soil would be rendered non-hazardous and return of the treated soil to the excavated area. This alternative would also require some additional backfilling on the site. The criteria affecting the decision to thermally treat the soil were based on contaminant properties and concentrations and the cost of transportation and disposal to an approved landfill. Based on these criteria, the soil contaminants had to be easily volatilized, be so diluted after treatment that no threat to the public or the environment exists and be in such low

concentrations that volatilization would not require excessive energy consumption and therefore higher operating costs.

PRETREATMENT PROCEDURES

To determine if the thermal treatment of site soils would work satisfactorily, a trial run was conducted using a pilot scale batch type heater that would accommodate approximately 0.25 yd³ of soil. Two test burns using the site soils were conducted. Chemical analyses before and after burning for 1,1,1 trichloroethane, trichloroethene and toluene showed greater than 99% removal for each contaminant. From this trial, it was determined the soil would have to be heated to 375 °F for a contact time of approximately 2 mm for effective removal. It was also learned that particulate emissions would be a problem with a full scale system.

The next task was to apply for an air discharge permit from the state. The state of Florida reviewed the unit specifications for air discharge permit requirements. Particulate emissions were to be removed by a cyclone followed by a cloth bag house. The air to cloth ratio was calculated for effective particulate removal. The emissions collection system was rated at 99% particulate removal efficiency by the manufacturer. Based on the air to cloth ratio and the 99% efficiency rating, the state approved the particulate collection system.

The expected volatile organic carbon (VOC) discharge levels were calculated from contaminant concentrations, soil feed rate and discharge gas flow rate. Worst case VOC discharge concentrations were assumed. To insure that the process did not pose a threat to the surrounding environment or the personnel operating the unit, an air monitoring program would be instituted during full scale operations.

The full scale thermal treatment unit met all the applicable air emissions requirements and the Florida DER advertised the proposed operating permit in the local newspaper as required. After the two week public opposition response time had expired without adverse comments, the state issued a temporary operating permit to the USEPA and the unit was mobilized.

TREATMENT UNIT DESCRIPTION

The contaminated soil was treated in an asphalt drying unit designed to dry raw materials as they enter an asphalt plant. The system (Fig. 1) included the asphalt preheater, a particulate collection system and a 500 KW generator for all electrically powered components on-site. A schematic block diagram of the treatment process is provided in Figure 2. The major components of the system are commercially available and only minor fabrication work was required.

Figure 1
Actual Treatment

The preheater was propane fueled and designed for a feed rate of 100 tons/hr, but was only operated at a rate of 10-15 tons/hr to comply with air discharge requirements. Liquid propane contained in a 5,000 gal tanker was sent through six 70 gal/hr vaporizers before being ignited at the preheater inlet. Unit operating parameters are given in Table 1.

PROCESS PROCEDURE

Because of limited space on-site, off-site treatment was required. Contaminated soil was excavated from the site and transported via 15 yd³ dump trucks to the treatment unit located at a county landfill in a remote area approximately 15 miles away. When necessary, the soil was initially spread in a contained area to dry and then placed into the collection hopper of the treatment unit. From the hopper, the soil travelled via a belt-driven conveyer into the preheater at a rate of 10-15 tons/hr. On the average, two dump trucks carried 130 tons of soil per day to the unit for treatment.

The soil was gravity fed through the rotating preheater; the fuel was burned at the other end. Agitated by the rotating action of the preheater and exposed to gas at 375 °F, the organics vaporized from the soil. Since the organic contaminants included combustible compounds, it is reasonable to assume that combustion as well as volatilization occurred during the treatment process.

The treated soil was collected in a bin and was characterized as a dry sand. To improve the consistency and add natural organic content, the soil was mixed with fill dirt from the landfill at minimal cost. The mixture was then returned to the site. For the entire tonnage of soil treated (1,670 tons), the average loss in soil weight was 20%. The majority of this weight reduction was likely due to moisture evaporation and charring of natural soil organics.

Particulate emissions from the treatment unit were collected in the cyclone and the cloth bag house. Some volatile material emissions were discharged into the surrounding atmosphere. Air monitoring was conducted during the second day of regular treatment operations to determine stack emissions and ambient air concentrations. Air samples to determine VOCs were collected from the stack gas, one position 900 ft upwind, and nine positions approximately 900 ft downwind in the radius of the stack plume path.

RESULTS

The treatment unit was used to effectively treat 1,670 tons of contaminated soil by reducing the concentration of volatile organics present. Concentrations of 1,1,1 trichloroethane, trichloroethene, toluene and xylene were reduced by at least 99% (Table 2).

Since the treated soil was returned to the site as fill, both disposal and major backfilling costs were avoided. Transportation of the untreated soil to the treatment site was included in the treatment cost, while the return of treated soil was excluded. The treatment price did not include operators and equipment for soil excavation and backfilling. Soil loading and unloading operations at the treatment site were also excluded.

The low level concentrations of organic emissions discharged to the atmosphere posed no threat to public health or the environment (Table 3). Stack samples contained VOC concentrations of 5,000 to 20,000 ppb for the major contaminants. The downwind samplers which intercepted the plume at ground level samples had a maximum level of only 8 ppb.

Effective volatilization of the contaminants required 6-10 gal of propane fuel per ton of soil. Thirteen operating days were needed to complete the soil treatment.

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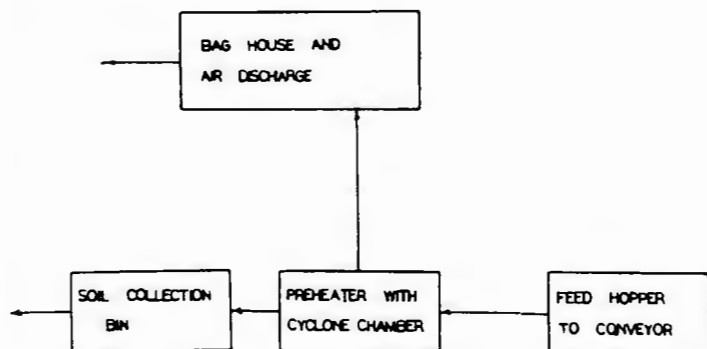
Figure 2
Flow Chart of Treatment Process

Table 1
Treatment Unit Operating Parameters

Parameter	Operating Conditions
Feed rate	10-15 tons/hr
Operating Temperature	375 °F
Total heat input	18.5 M BTU/hr
Stack gas discharge rate	22,725 ft³/min, 77 ft/sec

Table 2
Concentration of Major Contaminants in Untreated and Treated Soil

Chemical	Untreated (ppb)*	Treated (ppb)*
1,1,1 Trichloroethane	20,000	110
Trichloroethene	20,000	55
Toluene	61,000	200
Ethyl Benzene	10,000	18
M-Xylene	20,000	43
O&P Xylene	30,000	45

* dry weight basis

Table 3
Concentrations of Organic Emissions from Air Samples Taken at the Treatment Unit Location

Chemical	Stack (ppb)	Downwind* (ppb)	Upwind (ppb)
1,1,1 Trichloroethane	621	0.73	0.04
Trichloroethene	339	0.34	0.00
Toluene	5110	8.44	0.96
Ethyl Benzene	720	1.26	0.81
Methyl Ethyl Ketone	1900	1.09	0.54
Benzene	1700	3.29	1.94

*Represents highest detected concentration of several stations along the downwind plume. These monitors were approximately 300 yards downwind.

Table 4
Cost Comparison for Thermal Treatment vs Landfilling

Cost	Thermal Treatment	Landfilling
Transportation	none	$61/ton
Disposal/Treatment	$90/ton	$65/ton
Mobilization/Demobilization	$19/ton	none
Labor	$6/ton	none
Soil Loading Equipment at Treatment Unit Location	$1/ton	none
Total Cost:	$116/ton	$126/ton

Note: These costs do not include costs for excavation and backfilling. The treatment option required only 410 tons of additional backfill @ $0.50 per ton.

CONCLUSIONS

In this instance, thermal treatment proved to be a suitable technique. Site and operational characteristics that contributed to the success of the effort were:

• The site contaminants of major concern were solvents with relatively high vapor pressures

• Contaminant concentrations were sufficiently low so as not to require large quantities of energy in the treatment process
• The treatment unit could be located close to the site to minimize hauling distances.
• A remote treatment location was available to minimize the impact of emissions upon the general public or significant environmental resources
• Dry weather conditions, encountered during the operation, minimized down-time and allowed for dilution of volatile emissions before they could be "scrubbed" from the atmosphere by rainfall.
• A cooperative local and state government that quickly evaluated and approved the operations plan and set emissions criteria.

A cost comparison between the thermal treatment technique and the other identified alternative, landfilling, is found in Table 4. The cost savings over the latter was $10 per ton. Since the thermal treatment resulted in volatile chemical emissions, the technique is not without environmental trade-offs. However, in this instance, the temporary air discharges were judged less significant than the threat to public health via contaminated groundwater, and landfilling was not a final solution to the problem. Additionally, the discharges were in compliance with local and state regulatory standards.

The set up time was two weeks for this "first time" operation, but future mobilization could be accomplished in three or four days.

The feed rate was determined by the discharge gas rate and contaminant concentration. The 10-15 tons/hr throughput provided a sufficient rate for dilution of the volatile emissions. Soil contaminants were volatilized at relatively low temperatures; the highest vaporization temperature for any of the contaminants was less than 282° F. The preheater was operated at a temperature of 375° F.

During operations, few breakdowns occurred and the unit required little maintenance. Preventive maintenance was performed twice daily and consisted of lubrication and inspection of parts.

RECOMMENDATIONS

This thermal treatment method can provide an alternative to landfilling of contaminated soils. When choosing this option, some considerations may include:

• *Types of Soil Constituents and Contaminant Concentrations:* Some solvents produce toxic gases at low temperatures. Higher contaminant concentrations or contaminants that are less volatile would require longer throughput time and/or higher combustion temperatures, resulting in higher fuel consumption.
• *Treatment Location:* The stack discharge emissions must comply with state standards. Rainy weather may cause considerable problems with the discharge of volatile stack emissions. The volatile materials would be scrubbed from the gas stream by the rainfall thus inhibiting dilution and returning the contaminants back to the soil. Shut-down time would also be increased in the event of severe weather. The soil transportation cost was included in the price of treating the soil for this case, however transportation costs need to be kept reasonable. This treatment unit required at least 100 ft² of operational area.
• *Heat/Fuel Sources:* The unit could be operated with a variety of fuel sources, i.e., propane, diesel fuel or natural gas. The ultimate soil disposal option may require a clean burning fuel. Propane was used at this site so that backfilling with the treated soil would be possible.

ACKNOWLEDGEMENTS

FLOATING COVER SYSTEMS FOR WASTE LAGOONS: POTENTIAL APPLICATION AT OLD INGER SITE, LOUISIANA

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INTRODUCTION

There are many pits, ponds and lagoons at uncontrolled hazardous waste sites across the nation. With sufficient rain, these impoundments can overflow, resulting in the release of their chemical-laden contents to the environment. One approach to this problem involves pumping, transporting and treating enough of the impounded material to create a safe margin of freeboard between the remaining liquid and the top of the containment structure. These pumpdown/treatment measures are considered temporary, however, and are usually initiated to prevent damage to the environment while the site is undergoing investigation and ranking for eventual remedial action. They also can be expensive, costing between $0.10 and $0.40/gal[1], and are especially expensive if pumpdown/treatment is required several times before a final action can be undertaken at a site.

To address this problem, the Oil and Hazardous Materials Spills Branch (OHMSB) of the USEPA assembled cost and technical information on methods to prevent rainwater from entering these impoundments. The resulting report[2] on spillage control methods for waste lagoons concluded that conventional structural covers (i.e., metal buildings, air supported structures and cable structures) are not generally cost-effective for preventing overtopping of waste lagoons unless there are unusual circumstances increasing pumpdown/treatment costs. The report recommended the investigation of innovative structures, such as floating covers, as an alternative to pumping, transport and treatment of impounded liquids.

In response to the above-mentioned recommendation and a request from USEPA Region VI for information on this technology, OHMSB directed JRB Associates to: (1) perform a state-of-the-art review of floating cover systems and (2) recommend specific alternatives to prevent the potential overtopping of a waste lagoon at the Old Inger site near Darrow, Louisiana. This paper documents the result of these efforts and includes information obtained from actual site visits and from 15 cover/liner manufacturers and installers [3-20].

TECHNOLOGY DEVELOPMENT AND CURRENT USES

Floating covers were initially developed as an inexpensive method for covering potable water reservoirs to eliminate contamination from surface runoff and organic debris. The first patent was issued in 1967 to Globe Linings, Inc. for a design that allowed extreme fluctuations in liquid levels and drainage of accumulated rainwater from the cover surface.[28]

These covers were installed in many reservoirs during the late 1960s and early 1970s by various installation companies across the country. The first covers were made of either butyl rubber or a synthetic polymer called Ethylene-propylene-diene-monomer (EPDM) and were fitted with butyl rubber floats that required inflation.[12, 26] Current floating covers are composed of Hypalon or chlorinated polyethylene (CPE); however, other materials are also used for special projects.[3, 20] The old air-inflated rubber floats have been replaced by closed cell polyethylene floats.

In 1976, two additional patents were issued: one was issued to Burke Industries, Inc.; the other was issued to Globe Linings, Inc.[29, 30] The Bruke patent presented a new method for draining rainwater from a floating cover, while the Globe patent presented a new system for collecting gases from beneath covers placed over biodegradation ponds.

At this time, Globe Linings, Inc. has installed approximately 200 covers, while Burke and five other companies have installed about 100 more.[12, 16] These covers have ranged in size from about 15,000 to about 700,000 ft²; however, larger covers also have been installed. One cover, now under construction in the Los Angeles, California area, covers 2,000,000 ft².[3-20]

According to industry officials, approximately 80 to 85% of all floating covers have been constructed over potable water reservoirs.[12,16] The remaining 15 to 20% have been used on biodegradation facilities, slaughterhouse waste lagoons, chemical treatment ponds, toxic waste lagoons and fish hatchery ponds.[12, 16] The covers for biodegradation facilities were developed to collect methane gas for use in boilers or electric generators. Odor control was cited as the main reason for covering pits at slaughterhouses. Fish hatchery ponds were covered to prevent fishkilling algal blooms. Chemical treatment ponds and toxic waste lagoons were covered to prevent overtopping due to precipitation. Due to the proprietary nature of these activities, very little data were available on the types of chemicals or facilities involved in covering waste lagoons.

Regardless of where they have been placed, floating cover systems have shown a remarkable resistance to the elements at a very low cost. Average costs ranged between $2.50 and $3.40/ft²;[3-20] much lower than other available methods for covering large bodies of liquid.[2] In addition, many of the representatives stated that a 20 year guarantee was provided for their system.[6, 7, 12, 19, 20] The durability of floating covers is exemplified by a cover installed on a potable reservoir in Fort Saint John, British Columbia[12] which withstood the forces of 4 ft of ice and −40 °F temperatures for 2 months. (The temperature dropped to −65 °F for 3 weeks during that 2 month period.) Two other covers in Mobile, Alabama have been unaffected by winds up to 150 miles/hr.[18]

DESIGN OF FLOATING COVERS

As mentioned in the previous section, there are two patented designs for floating covers and an additional patent for the associated gas collection system. These designs, with slight modifications, have been utilized in virtually every floating cover system installed to date.

The Globe Design

The Globe design is primarily based on a rainwater collection sump that forms around the perimeter of the cover during a rainfall. Rainwater is directed toward this sump by various configurations of foam floats inserted and sealed into special pockets in the cover. The most common configuration consists of one long center float attached perpendicularly to smaller, lateral floats at about 36-ft centers (Fig. 1). After the perimeter sump fills with water, it is drained either by random pumping with a portable pump or by installing a flexible perforated hose in the area of the fold formed by the collected water. On large reservoirs, vertical cables have been strung from the reservoir bottom and attached to the cover to stabilize it against wind action.

The patented Globe gas collection system is designed for connection to the foam floats on the Globe cover. However, since all cover designs use the same type of floats, the Globe gas collection system could be fitted to almost any floating cover. The gas collection system consists of several air chambers formed at various points along the cover flotation system (Fig. 2). Each chamber is covered by the floating cover material and is equipped with openings that allow gases to flow up through the air chamber from the triangular-shaped space formed between the cover, the covered liquid and the side of the float. The upper end of the air chamber is connected to a short standpipe and then to a manifold pipe to allow pumping of gases.
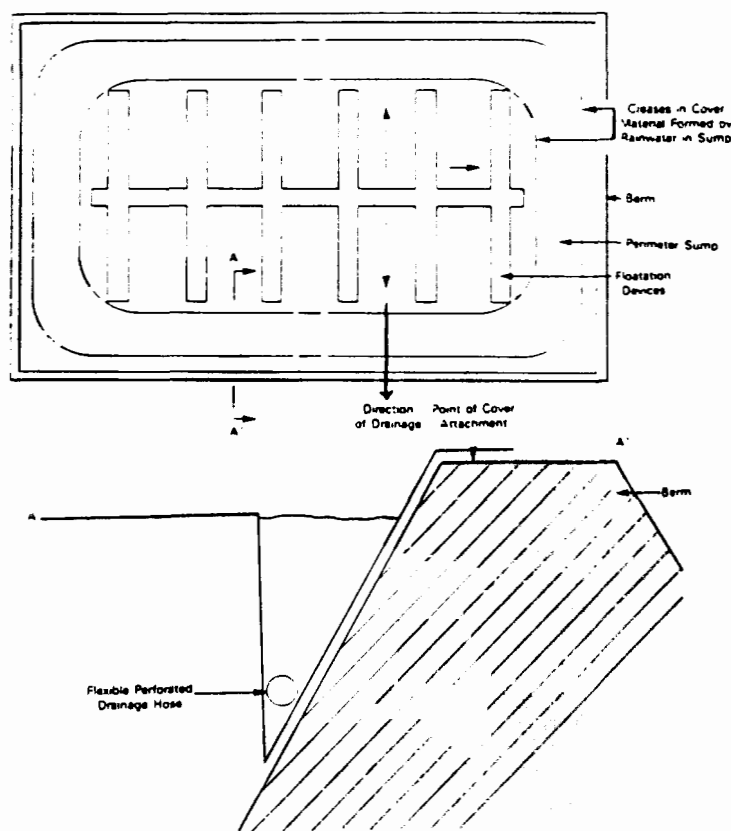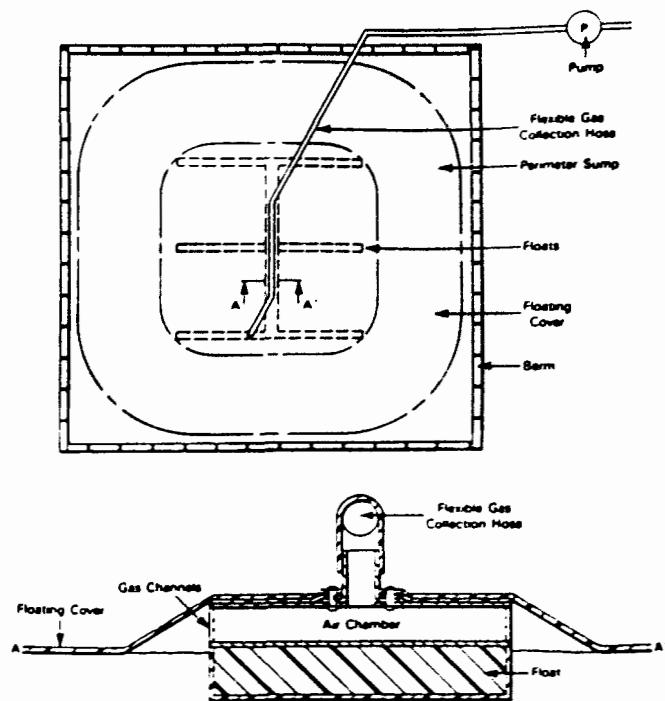
Figure 2
Schematic Overview and Cross-Sections of a Patented Globe Floating Cover and Gas Collection System Design (Redrawn from Kays,[16] Patent Number 3,980,199)

The Burke Design

The Burke design, presented in November, 1976, presents a completely different method of draining rainwater from the floating cover. It consists of channels in the middle of the cover created by strings of segmented sand-filled tubes that are held at a constant depth beneath the cover by floats on either side of the channel (Fig. 3). The sand-filled tubes lie underneath and are connected to flexible perforated collection tubes. Rainwater, after striking the cover, drains through openings in the floats and into the collection channels; then it is pumped off through the collection tubes. The dimensions for each component of the system are determined through a few simple equations that are based on the dimensions of the area to be covered. With the exception of the sand-filled tubes, the Burke design can be built with the same materials used in the Globe design.

MATERIALS OF CONSTRUCTION

About 90% of all floating covers are made with reinforced Hypalon, either 36 or 45 mils in thickness.[3-20] Hypalon is used because it is resistant to most chemicals and weather conditions, easy to seam in the field and among the least expensive of the potential material. After Hypalon was developed, EPDM and butyl rubber were abandoned due to cracking and seaming problems. The second most popular material for floating covers is reinforced 36 or 45-mil CPE.[19] This material costs about the same as Hypalon ($0.50 to $0.70/ft²) but is neither as easy to seam in the field, nor as durable. Because of these drawbacks, the use of CPE covers is declining.[19]

The main limitation of Hypalon, i.e., its low resistance to oil derivatives such as kerosene, diesel fuel and hydraulic fluids, led to the development of three other membranes. Two of these, used by Globe Linings, Inc., are called OR-EPA and HR-EPA.[12] Globe had no organized test data on either of these materials and declined to release the name of the manufacturer; however, a sample of OR-EPA appeared to be more resistant to stretching than samples of Hypalon. A representative of Globe stated that HR-EPA is stronger and resists more chemicals than OR-EPA, which is

Figure 1
Schematic Overview and Cross-Section of a Floating Cover Incorporating the Patented Globe Design
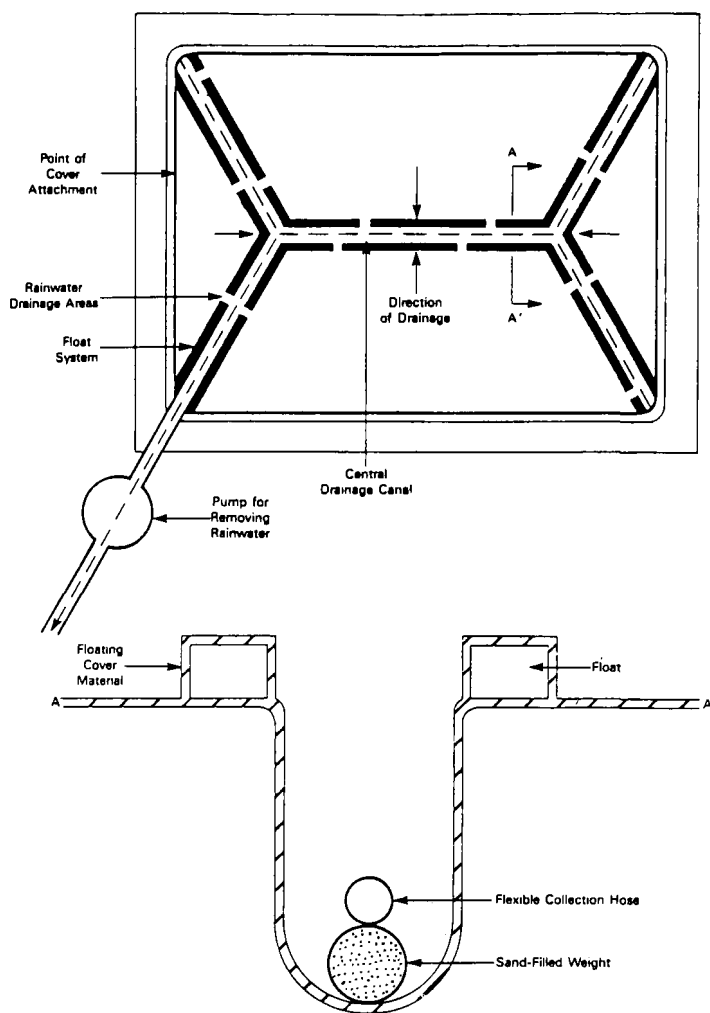
Figure 3
Schematic Overview and Cross-Section of a Floating Cover
Incorporating the Patented Burke Design (Redrawn from Burke, et al.,
1976, Patent Number 3,991,900)

stronger and resists more chemicals than Hypalon.[12] Those tougher materials are priced accordingly, with HR-EPA costing about $1.70/ft² and OR-EPA costing about $1.50/ft².[12] The Globe representative also stated that HR-EPA and OR-EPA are more difficult to field seam than Hypalon.[12]

The other alternative to Hypalon is XR5 made by the Shelterite Company. This material is highly resistant to a wide range of chemicals but, like the other alternatives to Hypalon, XR5 is more difficult to field seam and is about twice as expensive.

APPLICABILITY OF FLOATING COVERS AT THE OLD INGER SITE

The Old Inger Site is located near Darrow, Louisiana, between Louisiana Highway 75 and the Mississippi River levee (Fig. 4). Once an oil reclamation plant, this site was abandoned in 1978 and is now on the National Priority List. It has been the subject of a remedial investigation and will receive a state-led remedial action in late 1985 or early 1986.[2, 25]

The site contains a waste lagoon (Fig. 4), approximately 240 ft long and 150 ft wide, which has received several wastes from oil refining processes. This lagoon is only accessible on foot except for the northeast corner where a light truck may be able to reach the edge of the berm. Presently, the lagoon is filled to within 6 in. of the top; the liquid has three layers:

- A top layer, approximately 1.5 ft thick, composed of a floating oil emulsion
- A middle layer of oil-contaminated water that is from 3 to 8 ft thick
- A bottom layer of unknown thickness, composed of oil sludges and debris

The top layer has a thin hardened film that allows small objects such as rocks and sticks to roll across the lagoon surface when thrown. This thin film apparently allows rainwater to penetrate and gases to escape, but it does not permit any appreciable evaporation of water from the lagoon. Piercing through this top layer are long 2 x 4 in. beams, several hundred small bottles and approximately 50 55-gal drums. An analysis of chemical compounds contained in the lagoon revealed the presence of a large number of petroleum-derived compounds including a series of long-chain saturated hydrocarbons, polynuclear aromatics, phenols, aromatics and phthalate esters.[32]
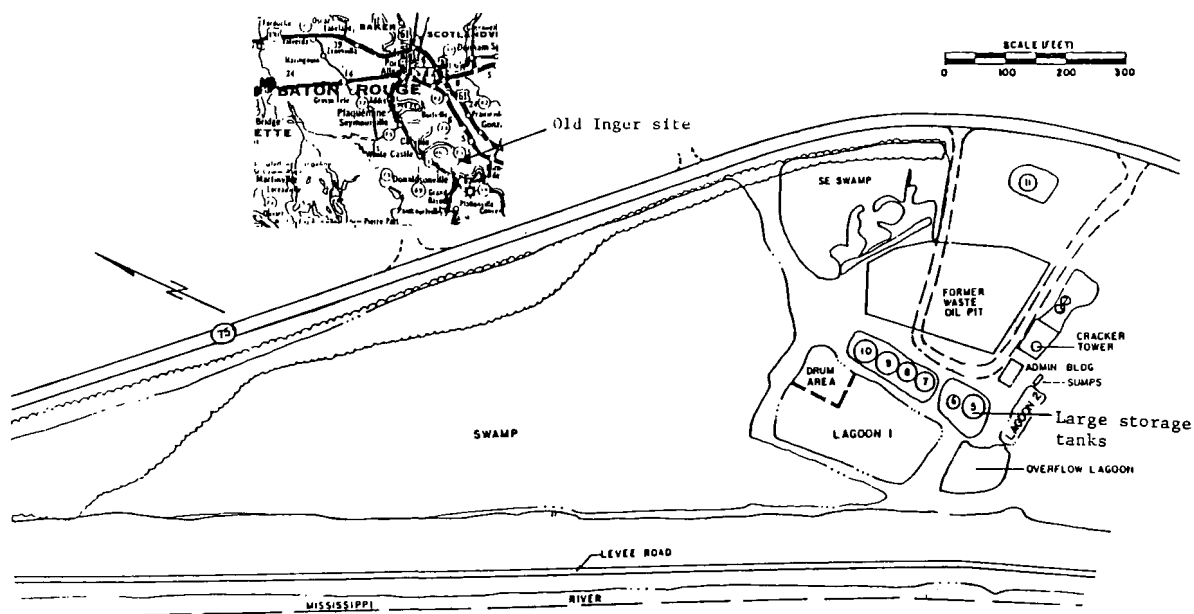
Figure 4
Old Inger Refinery, Site Location and Site Plan (From Law Engineering Testing Company)

The berm around the lagoon is approximately 5 ft high and 8 to 12 ft wide at the base. The width at the top is between 1 and 3 ft, just barely wide enough to allow one person to walk the perimeter. Materials used to construct the berm appear to consist of local earth (a silty, sandy clay). The average vertical and horizontal permeability of these soils is about 1 x 10⁻⁵ cm/sec (10 ft/yr).[11] It is not known whether any compaction techniques were used during construction or if any efforts were made to prevent sand seams from forming.

Furthermore, the north and west outside toe of the berm is covered with approximately 1 to 1.5 ft of water from an adjacent swamp. This swamp, which was contaminated by a breach in the lagoon berm in 1978, extends about 1500 ft north of the lagoon and connects with a large pasture by an overflow pipe that runs under Louisiana Highway 75. Since the 1978 spill, the swamp has periodically been contaminated by lagoon fluids seeping through a deep notch in the top of the berm.[11] This notch has recently been repaired.

Until November, 1983, Federal and state officials believed that the liquid level in the lagoon was fairly constant, subject only to overtopping from rainwater.[11] In July of 1983, an emergency action was conducted at the site to create about 2 ft of freeboard by pumping approximately 300,000 gal of the lagoon's liquid into three, on-site tanks. However, in late November, the area received several inches of rain and the fluid level of the lagoon dropped about 3 in.[11] Presently, there is no confirmed explanation for this drop which is still under investigation. Prior to the drop in fluid level, studies were being made on alternative approached to prevent the lagoon at Old Inger from overtopping.

Cost of a Floating Cover at Old Inger

Initial cost estimates for installing a floating cover over the Old Inger lagoon were low, i.e., between $2.50 and $3.50/ft².[3-20] However, when all the site conditions were evaluated and provided to 11 cover installation companies, only one cost estimate was received;[12] it was for $5.50 to $6.50/ft². Assuming a design area of approximately 36,000 ft² for the Old Inger site, the cost of a floating cover would be approximately $250,000. This includes the OR-EPA material cost (about $1.50/ft²); the combined costs of the patented float system and gas collection system (about $1/ft²); the installation costs for field seaming, float insertion and anchoring (about $1.00/ft²); and research and development costs for designing a site-specific anchoring and float system for the cover ($2 to $3/ft²).[12] These costs would have been lower if a less expensive cover material such as Hypalon ($0.70/ft²) could have been used and if site access and berm stability problems were not present. It is estimated that these factors almost doubled the cost of the cover system for the Old Inger site.

Alternative Solutions for the Old Inger Site

Other methods for controlling the potential overflow from the lagoon at Old Inger were evaluated. Cover systems made from steel, aluminum and wood were rejected because, at $10 to $20/ft², these systems would exceed the cost of pumping and treating the lagoon wastes. Air supported structural covers were also rejected on the basis of higher costs which would exceed $8,00/ft² of covered area.[12] Inflatible covers were rejected because the lagoon berm at the Old Inger site would probably not withstand the pressures that occur at the perimeters of these covers. Also, these covers require operation and maintenance of air pumps which would not be convenient for the Old Inger site.

Two additional alternatives considered for the Old Inger situation included "no-action" and continued periodic pumpdown/treatment as required. The "no-action" alternative would require no expenditures but would result in an increase in the level of contamination in the swamp surrounding the Old Inger site. The pumpdown/treatment alternative would cost approximately $110,000 each time, assuming that 2 ft of liquid (i.e., approximately 540,000 gal) would be removed at an average cost of $0.20/gal. If the level of the lagoon had not dropped during a recent

rain, and if 3 years were required for complete cleanup of the site, it is estimated that the lagoon would require at least seven pumpdown/treatment operations for an approximate total cost of $770,000. This estimate is based on 60 in. of annual rainfall and virtually no evapotranspiration from the lagoon due to the floating oil emulsion layer. Therefore, a floating cover would have been less expensive (at $6.5;/ft², the total cost would be approximately $250,000) than seven pumpdown/treatment operations at the Old Inger site if the level of the lagoon had not dropped.

CONCLUSIONS

Presently, the most common method of preventing overtopping of abandoned waste lagoons is pumpdown/treatment of the upper 2 ft of waste liquid. Costing between $0.10 and $0.40/gal, this method can be expensive, especially if it must be performed several times prior to final cleanup of a site.[1] Floating covers can be a more economical alternative; however, costs are extremely dependent on site-specific factors. Covers generally cost $3.50/ft².[3-20] Assuming that the combined cost of pumpdown, transportation and treatment is $0.20/gal; the price for one operation would be about 15% cheaper than a floating cover on the same lagoon. This cost relationship holds true for any size lagoon assuming vertical lagoon walls and pumping 2 ft of impounded liquid. Therefore, if the combined costs of pumpdown and treatment exceed $0.23/gal (i.e., $0.20/gal plus 15%), or if pumping is required more than once, then a floating cover may become the most cost-effective method of preventing overtopping of a lagoon. However, it is again emphasized that adverse site conditions may significantly increase the unit cost of a floating cover.

The engineering considerations associated with site conditions at the Old Inger site almost doubled the normal cost of a floating cover. However, this cost increase would not have caused the cost of a floating cover to rise above the costs estimated for pumpdown/treatment operations if the level of liquid in the lagoon had not dropped. The drop in lagoon liquid level at the Old Inger site is still under investigation. Unless site conditions change again, neither a floating cover nor pumpdown/treatment operations will be needed at the site.

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EVALUATION OF ADVANCED TECHNOLOGIES FOR TREATMENT OF CONTAMINATED SOILS

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INTRODUCTION

Many parcels of Army real estate have been contaminated by explosives, solvents and heavy metals wastes that reached the soil from various industrial operations. Examples of these waste-generating activities included equipment rebuilding and repair, munitions manufacturing and munitions disposal.

The Installation Restoration (IR) Program was established in the early 1970s to deal with potential soil contamination problems. It was evident that many of the chemical contaminants at Army installations were either unique to the military or were predominantly associated with the military. Acceptable limits for soil residues often were not established. Those that were established were determined on a site-specific basis through negotiation with the appropriate regulatory agencies. Very few processes for removal, decomposition or immobilization of soil contaminants are available or applicable to the Army's specific situations. A need for decontamination process development was recognized, and a number of unit processes were investigated under the IR Program established to meet this need.

The primary objective of the work reported in this paper was the identification of technologies: (1) not previously investigated by the Army; (2) which promised reasonable cost effective engineering solutions to specific types of soil contamination problems; and (3) which were potential subjects for further research and development within a set or predefined criteria.

APPROACH TO TECHNOLOGY ASSESSMENT

A structured technology evaluation methodology was devised. Of necessity, it utilized limited information and engineering judgment for execution. Two levels of evaluation were used. Each contained a number of steps.

Level 1—Conceptually Feasible Technologies

The objective of Level 1 assessment was to filter out those technologies which were conceptually applicable to decontamination of soils but which were not conceptually feasible within constraints peculiar to the Department of the Army.

Step 1—Classification and Categorization of Soil Contamination Situations

The objective of Step 1 was to define the array of soil contaminants expected to be treated by whatever technologies appeared most promising. Since few guidelines, criteria or regulations were available for acceptable soil residual levels for the chemicals of interest, there were, by definition, few if any soil contamination problems. Various situations did exist, however. They were identified by the actual or suspected presence of industrial chemicals not otherwise found in the soil of a particular site or by the actual presence of naturally occurring materials at higher than background concentrations.

Those situations having available data were evaluated. Generic types of soil contaminate profiles were developed. Classification and categorization of situations were made by types of contaminants and by the association between types. It was found that a predominant number of contaminated sites contained solvents, explosives and heavy metals intermixed. This was the generic situation used for all subsequent evaluations. Technologies showing promise for treatment of only one or two types of contaminants were identified separately and were not primary subjects for this effort.

Step 2—Identification of Conceptually Applicable Technologies

Unit processes or subsystems which appeared to be conceptually applicable to the treatment of one or more of the principal contaminant types were identified. This process produced an Initial Technology List. The List was amplified by developing background information and process descriptions for each entry. Technologies were categorized as thermal, chemical, biological or physical processes. Published and unpublished information were used. Information was displayed in a standard format to facilitate subsequent evaluation.

Step 3—Criteria Development

Level 1 assessment was conducted with a set of ten criteria characterizing the feasibility of applying a particular technology. Each criterion has three units of value (+, 0, −). A " + " was favorable, while a " − " was unfavorable. Specific definitions for each unit were devised to guide the engineers and scientists making the technology assessments.

The criterion of technology performance was used to assess a technology's ability to remove, fix or decompose a specific soil contaminant. Technologies with demonstrated effectiveness against any number of the contaminants of interest were rated high. Technologies with demonstrated ineffectiveness were rated low. This criterion was applied using best engineering judgment since quantified performance standards were not available at the time of the analysis.

+ -Demonstrated decomposition or removal of identified soil contaminants (e.g., explosives-related organics, heavy metals, solvents, PCBs and pesticides) to accepted levels

Table 1
Thermal Processes Considered for Level 1 Assessment

Technology	FY84 Status
Vertical well chemical reactor	AL
Multiple hearth incinerator	AL
Rotary kiln incinerator	SA
Molten salt incinerator	DV
Fluidized bed incinerator	AL
Wet air oxidation	AL
In situ vitrification	DV
Plasma arc torch	AL
Microwave plasma detoxification	DV
Burning/torching	SA
Low temperature thermal decomposition	DV
In situ hot air/steam stripping	DV
In situ microwave heating	DV
Laser-initiated thermal decomposition	DV
Supercritical water oxidation	DV
High temperature fluid wall reactor	DV

AL = Alternate technology (in use for other purposes but conceptually adaptable to soil decontamination).

DV = Developmental technology.

SA = State of the art technology.

Table 2
Chemical Processes Considered for Level 1 Assessment

Technology	FY84 Status
Sulfur-based reduction	AL
Reduction with sodium borohydride	AL
On-site solvent extraction	AL
Solvent extraction-Acurex Process	AL
In situ solvent extraction	DV
Decontamination of soils using the Franklin Solvent	DV
Free radical oxidation	AL
Free radical oxidation-Enercol Oxidation Process	DV
Fenton's Reagent	AL
Base-initiated decomposition	AL
Carbon adsorption	AL
Ion exchange	AL
Surfactant complexing	AL
Complexing with dithiocarbamate	AL
Philadelphia Quartz (PQ) complexing agent	AL
Complexing with cellulose xanthate	AL

AL = Alternate technology (in use for other purposes but conceptually adaptable to soil decontamination).

DV = Developmental.

SA = State of the art.

0 -Expected but not demonstrated decomposition or removal of identified soil contaminants

— -Minimal demonstrated or expected decomposition or removal of identified soil contaminants

The soils of interest had contamination profiles featuring both heavy metals and organic compounds. The criterion of versatility was used to rate the ability of a technology to successfully remove both organics and inorganics. This criterion did not attempt to rate possible contaminant interferences to performance.

+ -Demonstrated to decompose or remove both organic and inorganic contaminants of interest from soil

0 -Expected but not demonstrated decomposition or removal of both organic and inorganic contaminants of interest

— -Expected or demonstrated ability to decompose or remove both organic and inorganic contaminants of interest from soil

Table 3
Biological Processes Considered for Level 1 Assessment

Technology	FY84 Status
Microbial bioaccumulation of metals	DV
Immobilized cells	AL
Vermicomposting	AL
Composting	AL
Aerobic biodegradation	
-Activated sludge	SA
-Rotating biological contractor	SA
-Biopond	SA
Biological fluidized bed	AL
Landfarming	AL
Anaerobic biodegradation	AL
Anaerobic/aerobic cycling	AL
Adapted microbial cultures	DV
Vegetative uptake	DV
Bioreclamation of soils (GDS System)	SA

AL = Alternate technology (in use for other purposes but conceptually adaptable to soil decontamination).

DV = Developmental.

SA = State of the art.

Table 4
Physical Processes Considered for Level 1 Assessment

Technology	FY84 Status
Secure landfill	SA
Slurry wall	SA
Grouting	SA
Geological isolation	DV
Stabilization (chemical admixing)	SA
Microencapsulation	SA
Macroencapsulation	SA
High gradient magnetic separation	AL
Washout	AL

AL = Alternate technology (in use for other purposes but conceptually adaptable to soil decontamination).

DV = Developmental.

SA = State of the art.

Sometimes the volume of residuals produced by a technology is greater than the original contaminated volume, and a disposal problem results. The criterion of volume of residuals was used to rate a technology on its ability to reduce the volume of residual material.

+ -No additional residual volume generated

0 -Residual volume significantly less than volumes of treated soil

— -Residual volume equal to or greater than the volume of treated soil

Soil treatment technologies, while removing contaminants from soils, might produce residuals that must be further processed. The treatment or disposal of residuals may be more costly than the initial soil treatment. The criterion of a need for additional treatment was used to score each technology on its ability to produce nontoxic residuals. Systems that produced toxic residuals requiring further treatment were rated low.

+ -No additional treatment requirements

0 -Additional treatment for nontoxic or nonhazardous compounds required (e.g., effluent gas scrubbing for particulate removal)

— -Additional treatment for toxic or hazardous compounds required

A decontamination process may alter the conditions of the site, and this change may result in the movement of otherwise immobile contaminants to other media. This movement could then have an adverse effect on the local population, especially if groundwater becomes contaminated. The criterion of intermediate transport was used to rate technologies on their ability to minimize the spread of soil contaminants to another environmental medium.

+ -Demonstrated minimization of transport of contaminants between environmental media (i.e., air, water and soil)

0 -Unproven effects on intermedia transport

− -Demonstrated assistance to the transport of contaminants between media

It is possible that the operation of soil decontamination machinery or the application of a specific unit process may create unsafe conditions for the operators or for local residents. The safety criterion was used to evaluate a technology on its inherent safety implications for workers and local residents.

+ -No demonstrated hazard to workers or local residents during or after application

0 -Hazardous materials contained or controlled with minimum threat to workers or local residents during or after application

− -Demonstrated or strongly suspected hazards to workers or local residents during or after application

Since the volume of soils at contaminated sites is often very large, a process should be able to treat contaminants at an efficient rate. This criterion was used to rate each technology on its ability to decontaminate large volumes of soils within a reasonable time frame.

+ -Demonstrated ability to process large areas or large volumes of contaminated soil

0 -Adaptability to process large areas or large volumes of contaminated soil

− -Demonstrated or expected limitations on the area or volume of soil that can be processed

It is the goal of any decontamination technology to render a once-contaminated site safe for unlimited use. The criterion of future land use attempted to anticipate the results of the application of a technology to a given site. Sites that would be able to have unlimited public use upon completion of the treatment process rated high.

+ -Original contaminated site will have unrestricted public use after application

0 -Original contaminated site will have limited public use after application (e.g., industrial use)

− -Original contaminated site will be greatly restricted in use or access after application

Contaminated sites of interest often contained both organic and inorganic contaminants. It is possible that a process that successfully removed organics would not perform well in the presence of inorganics and vice versa. This criterion was used to rate technologies on their ability to perform in the presence of many contaminants.

+ -Demonstrated to be unaffected by the presence of other contaminants of interest

0 -Not expected to be affected by the presence of other contaminants of interest

− -Expected to be adversely affected by the presence of other contaminants of interest

A technology which could be designed to be modular or trailer-mounted was considered very attractive. Multiple sites could be serviced by the same hardware. A mobility criterion was used to rate a system's potential for a modular, transportable design of reasonable capacity.

+ -Demonstrated to be easily transported between sites

0 -Expected to be adaptable for transport between sites

− -Not transportable between sites

Step 4—Assessment Execution

Ballots were used in the evaluation process. All technologies conceptually applicable from the Initial Technology List were on the ballot. One ballot was prepared for each of the ten feasibility criteria. An assessment team comprised of chemical and environmental engineers, hydrogeologists and chemists was assembled. Each technology was presented to the assessment team twice: first, using the written detailed technology descriptions developed in Step 2, and then verbally by the project engineers. The verbal presentation was followed by discussions and completion of the assessment ballots. Voters were encouraged to include explanatory comments.

Ballots were collected and tabulated. Using the majority vote, one score (either +, 0, or −) was selected for each criterion for each technology. Written comments were used to resolve ambiguous scores. Technologies receiving more pluses than minuses were considered potentially or conceptually feasible. These technologies were subsequently evaluated for their research and development investment potential.

Level 2—Potential Research and Development (R&D) Targets

The purposes of Level 2 assessment were to: (1) discriminate between technologies that were commercially available and those that were developmental or conceptual at the time of the assessment, and (2) identify technologies that were worth further research and development investments.

Step 1—Criteria for R&D Investment Potential

Seven criteria were developed. A value system similar to that used for the Feasibility Criteria of Level 1 was used.

A critical programmatic goal under the IR Program was to be able to implement new technologies no later than during Fiscal Year 1987 (FY87). This criterion was used to differentiate between those technologies that were commercially available at the time of the assessment (FY84) from those which were anticipated or not anticipated to be ready by FY87.

+ -Commercialized or can be immediately adapted for removal or decomposition of soil contaminants of interest

0 -Expected to be commercialized for removal or decomposition of soil contaminants of interest by FY87

− -Unlikely to be commercialized by FY87

The criterion of proprietary status was used to differentiate between those technologies which were in the public domain (+) and those for which there were important or restricting proprietary aspects (−). The reason this criterion was included was because it would affect the ultimate cost of the technology developed.

+ -In the public domain

0 -In the public domain, but proprietary variations exist

− -Proprietary

In general, all of the technologies identified as conceptually feasible would require some level of R&D investment before they were ready for full-scale implementation. A criterion based on the estimated commercialization cost was used to evaluate the amount of R&D investment required to bring a specific technology from its FY84 level of development to full-scale implementation.

+ -R&D costs are comfortably within the expected budget

0 -Cost might stress the budget

− -R&D costs expected to exceed reasonable budget constraints

Estimated relative operational costs were difficult to quantify at the time of the assessment because there was insufficient information available. This criterion utilized the rating team's best estimate of operational costs using a secure landfill as the basis for comparison.

+ -Less than disposal in an off-site secure landfill

0 -Approximately equal to disposal in an off-site secure landfill

− -Significantly greater than disposal in an off-site secure landfill

The application of a technology to a contaminated site will always have some affect on the area's ecology. A criterion based on environmental impact was used to assess the ability of a contaminated site to recover after application of a specific remedial action technology.

+ -impact during application is insignificant or within reasonable limits, with complete ecological recovery after application

0 -Adverse impact during application with full ecological recovery expected after application

— -Significant adverse impact during application with only partial ecological recovery expected after application

Many times, removal technologies are contaminant-specific. A cleanup technology may be able to remove only a select group of solvents, for example. Given the contamination profiles anticipated at various Army installations, it might be necessary to employ several technologies to remove all contaminants at a specific site. This criterion assessed the ability of each process to either stand alone or be easily linked with other unit processes.

+ -Either stand-alone or easily linked with other unit processes

0 -Unknown capability to be linked with other unit processes

— -Cannot easily be linked with other unit processes for development of a system; linkable only in disjointed or discontinuous systems

Versatility was a criterion also used in the Level 1 assessment. It was used in the Level 2 assessment to further point out the ability of technologies to remove both organics and inorganics from contaminated soils.

Four questions on topics warranting further consideration were included in addition to the set of seven evaluation criteria. The questions were not discriminatory in the sense that technologies would survive or fail Level 2 assessment, but they were felt to be relevant to final recommendations on R&D investments.

• Is process equipment, hardware, software or a demonstration system currently available for field demonstration or pilot-scale testing? (Yes/No)

• Can reliability be designed into the hardware/software subsystems without exorbitant expense? (Yes/No)

• Are exotic or strategic materials required? (Yes/No)

• Are there materials handling risks to be assessed? (Yes/No)

Step 2—Level 2 Assessment Execution

Ballots were again used in the evaluation process. The same assessment team that evaluated the conceptually feasible technologies was used in this second evaluation process. Ballots were prepared for each of the technologies. Each ballot contained the seven assessment criteria and the four nondiscriminatory questions detailed under Step 1.

The time required to bring a given technology to full-scale implementation was the most important discriminator in Level 2 assessment. Technologies or unit processes which required more than four calendar years for commercialization were eliminated from further consideration. Technologies meeting the time to commercialization criterion were given further consideration. Ultimately, technologies that could be fielded within a minimum timeframe (fast track) and those which could be fielded within the four-year time constraint (medium track) were sought.

Level 2 assessment was made on the basis of information used for Level 1 and new information obtained between evaluations. Conflicts in scores were resolved by referring to evaluator comments accompanying each rating.

RESULTS OF TECHNOLOGY ASSESSMENTS

Initial Technology List

The technologies which were judged to be conceptually applicable to the removal, fixation or decomposition of military unique or relevant soil contaminants are listed in Tables 1 to 4. For further information, the reader is referred to the report of Bove, et al.[1]

Of the 55 technologies listed, 25 were judged to be conceptually feasible for consideration as potential R&D investment targets (Table 5).

Fast track and medium track technologies were the first results of Level 2 assessments (Table 6). Fast track technologies were those which were judged to require the minimum time to full-scale utilization. Medium track technologies were judged to be ready for

Table 5
Technologies Surviving Level 1 Assessment and Judged to be Conceptually Feasible for Removal of Military Unique or Military Relevant Soil Contaminants

Thermal Processes

In situ vitrification	High temperature fluid wall reactor
Rotary kiln incinerator	Microwave plasma
Low temperature thermal	Multiple hearth incinerator
Plasma arc torch	Super critical water oxidation
Fluidized bed incineration	

Chemical Processes

Solvent extraction (Acurex)	On-site solvent extraction
Free radical oxidation	In-situ solvent extraction
Franklin Solvent	Surfactant complexing
Fenton Reagent	On-site base-initiated reduction

Biological Processes

Composting	Vermicomposting
Landfarming	

Physical Processes

Secure landfill	Geological isolation
Macroencapsulation	Magnetic separation
Microencapsulation	

Table 6
Preliminary Level 2 Assessment Results for Fast and Medium Track Potential Research and Development Targets

Fast Track Developmental Targets

Secure landfill	Rotary kiln incinerator
Multiple hearth incinerator	Microencapsulation
Macroencapsulation	Landfarming
Fluidized bed incineration	Composting
Vermicomposting	

Medium Track Research and Development Targets

Geological isolation	On-site solvent extraction
Surfactant complexing	Fenton reagent
Base-initiated reduction	Free radical oxidation
In situ solvent extraction	Low Temperature thermal
Acurex Process	In situ vitrification
High temperature fluid wall	Microwave plasma
High gradient magnetic	Plasma arc torch
Franklin Solvent	

full-scale application within the four-year time constraint, but they required more testing and investment than the fast track technologies.

Whether the Army invests R&D funds in one or more of the technologies listed in Table 6, depends upon a number of factors such as redundancy between candidate topics, acceptability to Department of the Army from a regulatory viewpoint, projects in progress and work planned or in progress by other government agencies.

ACKNOWLEDGMENT AND DISCLAIMER

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ALTERNATIVES FOR DISPOSAL OF UNKNOWN GASES, CHEMICAL CONTROL CORPORATION SITE, ELIZABETH, NEW JERSEY

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INTRODUCTION

Compressed gas cylinders containing unknown or highly toxic material are being discovered at an ever increasing rate. They have been found at waste disposal sites, research facilities, landfills, military installations and a variety of other locations. Although the total number of this type of cylinder is not high, the potential for an uncontrolled release of highly toxic gases poses significant problems.

The Chemical Control Corporation Superfund site in Elizabeth, New Jersey is an example of a site where waste gas cylinders pose continuing disposal problems. The initial remedial actions taken at the site were confounded by the discovery of compressed gas cylinders with unknown contents. Efforts by the State of New Jersey, the USEPA, the U.S. Army Corps of Engineers and private contractors to permanently dispose of the cylinders have been unsuccessful to date.

One-hundred and eighty unidentifiable compressed gas cylinders in varying degrees of deterioration were discovered following the 1980 fire at the Chemical Control Corporation site. The variety of cylinder types present at the Chemical Control site ranges from aerosol cans and lecture bottles to large propane-type tanks. The cylinders lack any identifying markings, are in poor structural condition and typify the kind of cylinder which can pose serious problems to those faced with disposal responsibilities.

Transportation of unknown materials over public thoroughfares is prohibited by Federal law for interstate movements and by most states for intrastate shipments. To transport cylinders containing unknown gases for the purpose of disposal by detonation or any other means involves obtaining special transport permits and emergency waivers. In addition, special precautions such as police escort, coordination with local emergency services (police, fire departments and civil defense) and transport along prescribed routes during low-flow traffic periods are generally required.

In developing the specifications for remedial action at the Chemical Control Corporation site, a number of different options were examined for disposal of the compressed gas cylinders. A majority of these options were eliminated by the unknown nature of the cylinder contents. Without exception, commercial facilities specializing in gas cylinder disposal refused to accept the gases without prior knowledge of their exact nature. Military decommissioning facilities would not accept the material in accordance with Department of Defense policy and directives regarding the acceptance of non-military hazardous materials for processing. On-site disposal schemes have also been dismissed as too risky considering the businesses and residences near the site. Given these limitations, it became evident that sampling and analysis of the cylinder contents was necessary prior to disposal of the cylinders and any gas they might contain.

Sampling and Analysis

Sampling the cylinders by simply opening the valves (if this was even physically possible) was dismissed because an uncontrollable release leading to significant environmental contamination could occur if the valve should break internally, break off at the neck of the cylinder or open and not close again. Two potentially acceptable mechanisms for accomplishing this type of sampling were available: (1) Cold tapping of a new valve into the side of the cylinder and (2) Utilization of a cylinder rupturing device in a controlled environment.

Cold tapping was deemed too dangerous due to inherent dangers in the technique and the deteriorated condition of the cylinders. The technique of sampling the cylinders using a cylinder rupture unit is still under consideration as the technology is currently being developed.

In some cases, one may speculate on the contents of cylinders after examining the type of cylinder and valving (e.g., port size and thread arrangement). The problem with this approach is that the cylinder often is not holding the type of gas for which it was intended; a cylinder may have been used as a receptacle for other gases or the cylinder may be a "hybrid" made up of parts and components from different cylinders. Efforts to identify the cylinders and their contents based on visual inspection were unsuccessful due to the degraded condition of the cylinders after exposure to the original fire and subsequent weathering.

The principal problems in handling these cylinders stem from:
- Deteriorated physical condition
- Non-functional or damaged valve mechanisms
- Obliterated identification markings
- Evidence of non-specified refilling (i.e., type A gas placed into type B cylinder)

Any one factor or a combination of factors can pose serious problems in sampling and identifying the cylinder contents. Identification of the cylinder contents is a critical step for handling, transportation and proper disposal.

CYLINDER DISPOSAL ALTERNATIVES

The proper disposal of waste cylinder contents depends on the nature of the waste. Many different alternatives are available for cylinder disposal after determining the nature of the contents.

Commercial facilities are readily available for handling various contents via either incineration of pyrophoric gases and liquids or chemical treatment/neutralization of non-pyrophoric contents.

Some non-hazardous gases may be simply vented to the atmosphere. Each of these alternatives, however, requires that the nature of the cylinder contents be known for safe and effective handling.

Venting

Various gases such as nitrogen and helium may be safely released to the environment merely by releasing the contents through the valving mechanism or via cylinder rupture. This option is simple, inexpensive and the technology is readily available to open or rupture the cylinders.

Prior to any venting operation, however, the nature of the cylinder contents must be known. A great many industrial and research gases have hazardous characteristics which would make their release catastrophic. The consequences of such a release would be particularly severe in a heavily populated area such as the town of Elizabeth, NJ.

Incineration

Incineration is a technology which can be employed for disposal of flammable gases and various biological materials. Commercial incineration facilities capable of handling many of the flammable gases are readily available and costs are minimal for this type of disposal.

Incineration disposal technology may only be employed for pyrophoric gases (such as acetylene and hydrogen sulfide), liquids and certain biological materials. Again, it is essential that the nature of the waste be known, this time in order to determine the effectiveness of the combustion process. Even among various flammable gases, the exact nature of the combustion process is dependent upon the waste type as gases are destroyed at different temperatures, some react explosively and some produce hazardous byproducts upon heating and combustion.

Incineration is not a viable disposal alternative for the cylinders located at the Chemical Control Corporation site without sampling and analysis of their contents. In addition, commercial incinerators will not accept pressurized containers due to the potential for explosion of a cylinder upon heating. Every incineration facility contacted declined acceptance of these cylinders, citing concerns over potential liabilities, safety and permit restrictions: (1) the cylinders contained unknown gases and (2) processing pressurized containers in an incinerator poses difficulties.

Chemical Treatment

Chemical treatment or neutralization can effectively be employed for most compounds and gases. Commercial facilities with a wide variety of treatment processes are available. At least one facility capable of treating industrial gases is located in the geographical area of the Chemical Control site; several other sites are located across the country.

Like incineration, effective chemical treatment or neutralization requires that the nature of the waste requiring treatment be known. A single process or even series of processes cannot insure that all types of wastes will be effectively handled. For each waste, there is a specific process which will most effectively treat or neutralize that particular chemical compound.

The potential for a wide range of toxic wastes to be present at the Chemical Control site eliminates the utilization of existing commercial facilities for processing these cylinders. All commercial facilities contacted about the cylinders declined to accept them prior to sampling and analysis.

On-site chemical treatment is similarly impractical because of the wide variety of wastes potentially present. It would not be possible to devise a process or series of processes capable of handling the range of potentially present compounds. Additionally, construction of on-site treatment facilities would be costly and could not insure against environmental releases.

Ocean Disposal

The USEPA has approved the disposal of certain wastes at offshore locations. A disposal site which is approved for certain types of waste is located at the 106-mile marker off the Atlantic coast. This disposal alternative would require recontainerization of the cylinders and shipment to this location.

Ocean disposal of the cylinders would provide a simple and fairly inexpensive means of disposal. The chemical Control site which is located adjacent to a waterway would be easily accessible by barge. Overland transport of the cylinders (and the associated risk of exposure along the route) could be eliminated using this option.

This disposal alternative presents potentially great environmental risks. Many gases commonly used in industrial and research applications are reactive in water. The incompatibility of these wastes with other wastes disposed of at this site is also a potential problem. Of far greater concern is the potential for release of biological or virological agents from the cylinders into the ocean environment. For these reasons, the USEPA representatives have stated that under no circumstances would the ocean dumping of any unknown wastes be approved.

On-site Detonation

On-site detonation at the Chemical Control site represents the most direct means for disposal of the compressed gas cylinders. This could be implemented by evacuating the nearby populated areas and setting shaped explosive charges on each cylinder.

The explosive release of unknown gases could pose extreme hazards to the environment and any nearby populated areas. It is impossible to predict the exact consequences of the release of unknown gases or liquids. While construction of various types of containment structures would help minimize release of contaminants and provide some control over the release, the ultimate effect would be to disperse the contents into the environment at the site.

Detonation of non-pyrophoric gases such as phosgene and boron trifluoride could result in spreading these gases over a wide area. Gases such as phosgene and chlorine, which are heavier than air, tend to accumulate in low-lying areas and could potentially pose significant health hazards upon release of a sufficient quantity. These potential hazards prevent on-site detonation from being a viable alternative.

Off-site Detonation

Off-site detonation represents the only presently existing and tested disposal technology for handling gas cylinders of unknown contents. In the past, this was the principal method employed for disposing of this type of cylinder. The technology for implementing this alternative is readily available and has been employed in the past for disposing of known gases contained in cylinders. With the increase in the number of cylinders requiring disposal plus greater environmental and safety awareness, however, this option is no longer acceptable. During the initial remedial action at the Chemical Control site, administrative project personnel proposed detonation of the cylinders at a remote location in central New Jersey. This plan was subsequently rejected, however, in view of health and environmental considerations.

The detonation process can be used in conjunction with other techniques to minimize the risks associated with this type of disposal. A bunker may be constructed to contain the explosions, reduce the noise and limit the spread of contaminants. The detonation can also be used to simultaneously ignite gasoline and other combustibles to aid in the destruction of certain types of flammable gases. The technique can be varied slightly to provide for a non-explosive rupturing of the cylinder structure with subsequent ignition in the detonation structure.

The greatest disadvantage of using the detonation and pyrolysis techniques for cylinder disposal is the incompatibility of many common gases with this disposal method. Flammable gases constitute only a portion of the hazardous gases and wastes potentially present in the cylinders. Many of the more toxic gases would be completely unaffected by the technique and could be uncontrollably spread into the environment. Non-flammable, liquified

gas could also be released over large areas through explosive releases. Many toxic virological agents would be unaffected by the fire and could be released by the detonation. Even the flammable gases could produce toxic combustion by-products or react synergistically upon detonation to produce a much more powerful explosion.

Although the risks to populated areas can be minimized through selection of remote locations for detonation, the environment at the disposal site may become contaminated. This could require some type of remedial action and expose workers to hazardous conditions.

The viability of air monitoring which could be conducted on a real-time basis during a detonation operation is questionable. Quantified data of the releases could only be obtained at a later date through sampling and laboratory analysis, thereby minimizing its usefulness in protecting both personnel and the environment.

No commercial facilities are available or permitted for operations of this type. Disposal facilities contacted in this regard indicated that the cylinders could not be accepted due to permitting considerations and liability concerns. Past incidents of detonation have required special waivers and have been conducted on a one-time only basis at remote locations. Commercial firms are available to provide the detonation service prolvided the client can furnish a site. For these, Governmental facilities were considered as potential detonation disposal sites.

As a rule, Government facilities will not accept waste materials from non-Governmental sources for disposal. This directive may be waived in emergency cases when public health and safety are being threatened. In most cases, however, disposal by detonation or any other means on a Government facility should not be considered a viable option.

MILITARY OPTIONS

The Department of Defense (DOD) currently operates a gas cylinder decommissioning facility at Tooele Army base near Salt Lake City, Utah. This facility utilizes remote handling apparatus to unscrew the valves from a cylinder and release the gaseous contents into high temperature incinerators. The body of the cylinder is then heated to drive off any remaining material and the emptied cylinder is disposed of properly. Another facility of this same type is under construction at a DOD facility in the Pacific. These decommissioning facilities handle only DOD materials (principally gaseous warfare agents) and, in all cases, the contents of the cylinders are known prior to disposal.

Experimentation is currently under way utilizing low temperature liquified hydrogen and nitrogen to super-cool gas cylinders. The cylinders are essentially "frozen" and then crushed. The solidified gas and the cylinder body are then incinerated under high temperature.

The DOD also operates munition test ranges and artillery practice areas that could potentially be used in the disposal scheme for the cylinders. In accordance with government policies, however, these operational centers are restricted to military use only. The only exception to this directive would be in cases where there is an imminent threat to public health and safety. This restriction severely limits the usefulness of the military as a disposal option for non-military wastes.

CYLINDER SAMPLING ALTERNATIVES

Sampling of compressed gas cylinders is a risky procedure even under ideal circumstances. Several deaths and many injuries have resulted from attempts to sample cylinders even where the contents were known. The problems of sampling are considerably greater at the Chemical Control site where the cylinders are in a degraded condition and the contents are unknown.

Controlled Venting

In most cases, gas cylinders can easily be sampled using the valves on the cylinders. The contents can be slowly released into a sample container and the cylinder re-sealed after sampling. This sampling technique utilizes readily available technology and is inexpensive.

Sampling through the cylinder valves on older or degraded cylinders is a hazardous operation because of the potential for failure of the valve to re-seal. This technique may only be utilized where the valve mechanism is intact and in good operating condition.

The cylinders at the Chemical Control site are deteriorated to the point where this sampling technique is impractical. Most of the valve mechanisms were severely damaged by the explosion and fire and the subsequent weathering. The valve mechanisms which remain relatively intact exhibit evidence of weathering which renders their functional viability questionable.

Potential exposure of the local population to toxic gases would be greatly increased during sampling activity using the existing cylinder valves. The risk of an accidental release is high unless the sampling operation is carried out in a contained environment. This technique could best be employed at a remote location where the only exposure would be to properly protected handling personnel and the local environment. Obtaining an appropriate site for such an operation would remain a logistical problem.

In certain cases, a cylinder can be safely sampled by attaching a second valving component to existing connections on the cylinder valve. This can only be accomplished in situations where the primary valve housing is in good condition. This technique (termed the "Line-Purge" method) permits relatively safe and inexpensive cylinder sampling where it can be applied. The Line-Purge method would be impractical and unsafe, however, for most of the cylinders at the Chemical Control site.

Cold-Tapping of Cylinders

Cold-tapping is a technique which has been utilized to install valves and other connections to tanks and water lines. This technique has not, however, been successfully applied to high-pressure compressed gas or liquid structures. The pressures commonly found in compressed gas cylinders are incompatible with existing cold-tap technology. Cold-tapping of the cylinders at the Chemical Control site, especially in light of the degraded structural condition, would be extremely hazardous and impractical.

Cylinder Rupture Vessel

The design of a structurally secure and mechanically operable vessel for remote rupturing and recontainerizing of gas cylinders has been patented and is in the preliminary phases of fabrication. This device, termed the Cylinder Rupture Vessel (CRV), is presently being fabricated by a private corporation. The CRV unit consists of a pressure vessel which encloses the cylinders as they are ruptured in an inert atmosphere by means of a hydraulic punch. After the cylinder contents have been released, the gaseous and/or liquid phases are sampled and the residue recontainerized into secure containers. The entire operation is accomplished remotely in a secure chamber which provides a fail-safe containment system.

The risk of exposure to both operating personnel and local populations would be virtually non-existent during CRV sampling operations. The CRV is a completely mobile, self-contained unit and is able to process cylinders ranging from 1 to 24 in. in diameter. This device, when constructed and fully tested, will provide a safe alternative for sampling compressed gas cylinders.

TEMPORARY MITIGATION MEASURES

In order to minimize the risk of an uncontrolled leak of potentially toxic gas, the 180 gas cylinders at the Chemical Control site were overpacked into specially fabricated recontainers in July of 1984. The recontainers were designed, fabricated and certified under the ASTM pressure vessel code and consisted of a flanged cylinder, closed at one end by a hemispherical end cap. The blind flange top was fitted with a bleed-off valve and a pressure gauge to monitor any leakage of the gas cylinder after it was placed into the recontainer. A flat plate was attached to the end cap to allow the recontainer to be placed in an upright position for storage.

Use of specialized recontainers on deteriorated gas cylinders is acceptable as a temporary measure that should be used only to eliminate an imminent danger to public health and safety. The technology cannot be applied in lieu of final disposal since the problem cylinder has not been destroyed but merely temporarily contained.

CONCLUSIONS

Sampling, transporting and disposing of compressed gas cylinders containing unknown gases pose a significant problem. Cylinders are being discovered in increasing numbers as the national effort to cleanup toxic waste sites proceeds. In most cases, the problem is not as severe as at the Chemical Control site with 180 cylinders. It is the potential toxicity, however, rather than the quantity of cylinders at a site which constitutes the true hazard.

Options for disposal of compressed gas cylinders whose contents are not known are extremely limited. Uncontrolled release through rupture or detonation at remote locations has become an unacceptable option from both an environmental and public health standpoint. Commercial disposal facilities are available for gaseous compounds, but the gas being destroyed has to be identified prior to disposal as a prerequisite. Military decommissioning facilities exist but are unavailable to process any non-DOD waste material and are set up to handle only very specific waste materials.

The emphasis in handling unknown compressed gas cylinders has currently shifted to sampling the container contents so that the proper disposal method can be employed. Existing technologies for sampling gas cylinders, especially those in deteriorated condition, are inadequate. New methodologies, such as the CRV, and the Line-Purge method offer the most promising solutions to the problems of properly handling and disposing of potentially hazardous gases contained in unmarked or unidentifiable cylinders.

DETOXIFICATION OF SOILS, WATER AND BURN RESIDUES FROM A MAJOR AGRICULTURAL CHEMICAL WAREHOUSE FIRE

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INTRODUCTION

At 5:00 pm on Apr. 23, 1980, a fire broke out at the Hewitt-Ware Feed and Supply Company warehouse in Hillsboro, Illinois (Fig. 1). Because of the potential acute and chronic life safety threats and environmental impacts, local authorities contacted REACT for assistance in responding to this emergency. REACT was asked to provide safety recommendations, including designation of toxic corridors for evacuation; the firm was also requested to design and implement a comprehensive decontamination/remedial action program.

RISK ASSESSMENT AND IMMEDIATE RESPONSE

REACT engineers and scientists conducted an on-scene risk assessment which revealed that people downwind from the fire

Figure 1
Hewitt-Ware Feed and Supply Company. Undamaged Grain Elevator and Burned Agricultural Chemical Warehouse.

should be evacuated because of the potential formation of toxic gases including cyanide, phosgene, chlorine, fluorine, oxides of nitrogen and isocyanates.

Four hundred families were evacuated from a 6,000-ft toxic corridor formed downwind from the fire. Hillsboro schools were closed for the day. A hospital and nursing home located approximately 2,000 ft downwind from the burn-site were not evacuated due to potential risks of moving elderly people and hospitalized patients. However, all intake systems, windows and air vents in both facilities were closed during the fire to minimize the influx of toxic gases. Because of the proximity of these facilities to the fire, water was applied to the fire in an attempt to "knock down" toxic fumes and reduce the amount of toxic air pollutants in the cloud of smoke generated by the fire.
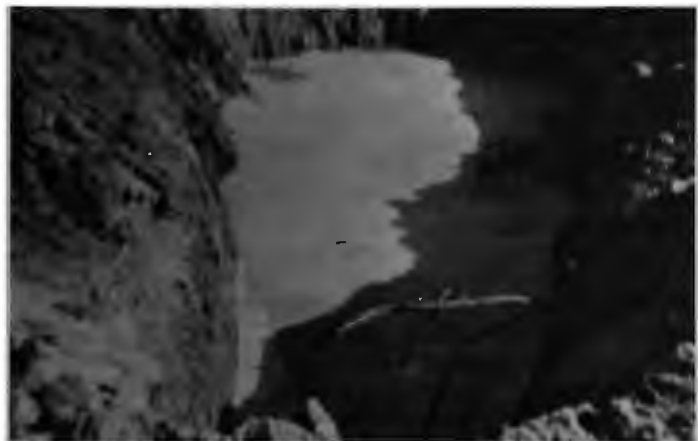
Figure 2
Containment Pits 1 and 2 Collect Concentrated Pesticide Runoff from Firefighting Operations.

Hillsboro City personnel took quick action to block drainage channels from the area; they also dug pits to minimize runoff of an estimated 250,000 gal of water used to extinguish the fire (Fig. 2). This quick action substantially reduced the water pollution potential from the highly contaminated water runoff. Using REACT's computerized toxic corridor projection system, evacuation limits were reduced from 6,000 ft to 2,000 ft 6 hr after the fire began, and finally to 800 ft 12 hr after the beginning.[19]

After the fire was extinguished, it was determined that a massive hazardous material cleanup program was required to eliminate public health hazard from the remaining unburned pesticides and the contaminated water.

Fire fighting operations had caused a water main between Schram City and Hillsboro to collapse. Two valve pits adjacent to the fire filled up with contaminated runoff. This situation posed an imminent direct cross connection problem with the drinking water systems of both Schram City and Hillsboro. To mitigate this problem, the valve pits were immediately drained, the distribution lines were back flushed and service was restored. City workers constructed a temporary dam to prevent contamination of downstream water supplies, a potential fish kill and threat to livestock. However, 300,000 gal of surface waters of Shoal Creek were contaminated above the dam.

ISOLATION AND CONTAINMENT

Contaminated stream waters were isolated and transferred into a 300,000 gal polyethylene-lined lagoon (Fig. 3). The interceptor trench collection network at the site of the fire was lined with bentonite/sand bags and activated carbon. Water in the primary collection pit at the site was pumped in to 55-gal drums pending the results of on-going treatability investigations (Fig. 4). Swales were constructed to divert the uncontaminated portion of the watershed around the contaminated area. Due to impending thunderstorms, a plastic canopy was used to cover the entire burn site to prevent contaminant transport off-site.

TREATMENT AND DISPOSAL

Twenty-one different pesticides, including 11,000 lb of granular chemicals and 3,465 gal of liquid chemicals, were involved in the fire. Since these products had been exposed to high temperatures, the exact physical/chemical and toxicological properties were unknown. The known quantities and properties of the material present before the fire are presented in Table 1.

The presence of numerous known and unknown complex organics required the pragmatic selection of physical/chemical and biological indicator decontamination yardsticks. Five pesticides were selected (Table 2), based on their relatively high aquatic and mammalian toxicities and water solubilities. Gas chromatographic analyses were performed on samples extracted from the fire debris on each of the five selected pesticides. Sample spikes were conducted along with the evaluation of samples to provide good laboratory quality control.

Aquatic bioassays were performed to determine the presence of any unknown contaminants and to confirm detoxification operations. Five waste streams were identified, and alternative recovery, treatment and disposal methodologies were considered. Ultimate treatment criteria were based on bench-scale tests; key to the analyses were treatment efficiency and cost. Pesticide detoxification alternatives included: aeration, evaporation, solar oxidation, photolysis, carbon adsorption, alkaline hydrolysis, chemical precipitation and oxidation with hydrogen peroxide. Five waste streams were identified for treatment: contaminated stream waters; concentrated leachate at the site; soil from the site; contaminated and uncontaminated building materials; and contaminated product residues.

Contaminated Stream Waters

A pumping station was constructed to transfer the contents of the stream into a 300,000 gal treatment lagoon constructed adjacent to the stream. This lagoon functioned as a batch reactor for

Figure 3
300,000 Gallon Treatment Lagoon Containing
Contaminated Runofff from the Creek.
The lagoon was lined with 24 mil Visqueen with side slopes of
1.5 to 1. Pumping station transferring creek to treatment lagoon,
final grade lagoon apron.

the following treatment operations: aeration, solar oxidation, evaporation, adsorption and clarification. Circulating pumps were utilized in the lagoon to accelerate pesticide degradation.

After four days of aeration, evaporation and solar oxidation, the following results were obtained:

| Pesticide | Concentration | | Removal Efficiency, % |
	Initially	After Treatment	
Atrazine	40	7.4 mg/l	81.5
Dyanap	24,034	5 μg/l	99.9 +
Treflan	1629	5 μg/l	99.7
Amiben	894	15.1 μg/l	98.3
Paraquat	3.1	0.260 μg/l	91.6

Powdered activated carbon was injected into the lagoon at a self-flocculating concentration of 1,000 mg/l (Table 3). This carbon dosage produced a clarified effluent with a suspended solids concentration of less than 10 mg/l. Consequently, post-filtration was not required prior to discharge. A carbon contact period of 4 hr was employed following a 48 hr clarification period.

Powdered carbon addition further reduced pesticide concentrations in the lagoon as shown below.

| Pesticide | Concentration | | Carbon Removal Efficiency, % |
	After Aeration	After Carbon	
Atrazine	7.4	0.06 mg/l	99.2
Dyanap	5	0.5 μg/l	----
Treflan	5	0.17 μg/l	96.6
Furidan	15	.01 μg/l	99.3 +

The treated water from the lagoon was then pumped behind a sandbag carbon/bentonite impoundment constructed in the stream. Powdered activated carbon was injected into the impounded waters to further reduce Treflan and Atrazine levels below detection limits to 0.1 μg/l and 0.01 mg/l respectively.

Static aquatic bioassays were run on 5 gal samples collected from the lagoon and creek impoundment following carbon treatment. Perch fingerlings were used in the bioassay because they were indigenous to the area. Five fingerlings were placed in each bioassay, and deaths were recorded with time. A control bioassay was run parallel to the test bioassays to identify potential interferences due to oxygen deficiencies or organism sensitivities and to isolate these factors from toxicity effects.

The waters in the area (an old strip mining area) had a pH of 4 to 5; the pH had to be adjusted to 7 to avoid a shock to the fish. Elevating the pH formed an iron hydroxide floc which may have removed some additional toxic materials via chemical precipitation. Another potential interference with these bioassays may have been the introduction of air into the bioassay cells resulting in stripping of volatile toxics.

Nevertheless, the bioassays indicated that no acutely toxic materials remained in the treated effluent lagoon or stream waters. In addition, the concentrations of chemicals in the water were reduced below any reported TL_m or LC_{50} (concentration producing 50% organism mortality). Survival times were recorded over 360 hr and, prior to test termination, over 50% of the fish population was surviving.

A pool located in Shoal Creek, one mile downstream from the lagoon discharge point, contained perch fingerlings. This pool was

Table 1
Chemical Quantities, and Toxicological and Physicochemical Properties of Products

Pesticide Trade Name	Chemical Class	Quantities (gal)	(lb)	Solubility @ 25°C Water (mg/l)	Solvent	TLV (mg/m³)	LD₅₀ (mg/kg) Oral (rat)	Dermal (rabbit)	TLM 96-hr (mg/l)
Treflan	Dinitroaniline	530			Xylene		3,700		0.02
Sutan	Thiocarbamate	140		E			3,690–4,500	4,640	
Surflan	Dinitroaniline		80	NS	Ethanol		10,000		
Paraquat	Pyridilium	56		S	NS^a	0.1	150		10.0
N-Serve	Pyridine	75		NS	Xylene	10.0	2,140	5,000	
Lorsban	Organophosphate	310	1,100	2	Methanol	0.2	2,000	4,000	
Lasso	Acetanilide	70		DISP	Monochlorobenzene	0.75	1,800		
Eradicane	Thiocarbamate	40		NS			2,000	3,830	
Furloe-Chloro IPC	Phenylcarbamate	10		NS	Xylene	100.0	3,800	10,200	10.0
Furadan	Carbamate		1,100	700	N	0.1	11	10,200	0.11
Lorox	Phenyurea		2,000	75	Xylene		1,500–4,000		
Lexone	s-Triazine		1,500	1,200	Ethanol		4,000	2,000	
Bladex	s-Triazine		200	NS		0.5	334	7,200	
Amiben	Benzoic acid	190	4,000	S	Alcohol		3,400–5,620	3,160	
Dyanap	Phthalic acid	370		S	Ethanol		232	400	0.10
Aatrex	s-Triazine	1,355	850	70	18,000 Methanol		3,080	10,200	1.0
Alfa-tox	Chlor. Hydrocarbon & organophosphorus	60		40	S Alcohol		2,000	8,000	
B 1088		4							
Banvel K	Benzoic acid	55		SS	Xylene		2,500	2,000	
Bassagran	Benzothiadiazin	200		620,000	Ethanol		1,480	2,500	
Randox	Acetamide		250	N			750		
Total		3,465	11,080						

^aDISP = dispersible; N = negligible; NS = not soluble; S = soluble; SS = slightly soluble; E = forms emulsion.

Table 2
Initial Contaminant Levels by Location and Decontamination Yardsticks

Sample Location & Date	pH	TOC (mg/l)	Alkalinity	Oil & Grease	Suspended Solids	Atrazine (mg/l)	Dyanap (μg/l)	Treflan (μg/l)	Amiben (μg/l)	Paraquat (mg/l)
Burn Site Collection Pit No. 2, 4/29/80	7.1	400	160	108	18	40	24,034	1,629	894	3.1
Lagoon, 4/29/80 (Note: 4-days treated)	4.4	30	0	10	156	7.4	<5	5	15.1	0.260
Creek, Station 4, 4/29/80 (Note: 4-days treated)	7.1	22	150	5	34	4.9	121.7	7.5	16.9	0.340
Decontamination Yardsticks	4.0^a	10	0–100	5	20	<0.1	<100	<100	<100	<0.1

^aLow pH due to strip mine waters in area.

Table 3
Treatability Alternatives Resulting in Selection of Powdered Activated Carbon Addition for Water Treatment

Treatment Method	Dosage Level	Atrazine (mg/l)	Treflan (μg/l)	Contact Time (hr)	Sludge Volume (% volume)
Untreated Lagoon Sample		7.4	5.0		
PAC^a	24,500 mg/l	<0.1	<0.1	10.5	13
PAC	1,000 mg/l	<0.1	<0.1	0.5	0.5
PAC	5,000 mg/l	<0.1	<0.1	0.5	3
PAC	15,000 mg/l	<0.1	<0.1	0.5	8
H₂O₂^b	0.03%	<0.1	0.18	15.0	4
H₂O₂	0.3 %	<0.1	<0.1	15.0	4
H₂O₂	3.0 %	0.11	<0.1	15.0	4
Na₂CO₃^c	5 ml/l saturated solution	0.26	<0.1	24.0	20

^aAqua Nuchar powdered activated carbon, particle size 2 microns.

^bHydrogen peroxide—rejected because of potential formation of oxidized toxic by-products and high sludge volume.

^cSoda ash—rejected because of inadequate treatment and high sludge volume.

utilized for an in situ bioassay. No adverse effects were monitored during cleanup operations. Treated water was released after confirming tests indicated that concentrations of monitored contaminants had been reduced below maximum allowable concentrations (Fig. 5 and Table 4).

The 2300 gal of concentrated carbon/bentonite slurry were pumped from the lagoon bottom into expoxy-lined 17H drums for disposal. Unpumpable residues (500 gal) were treated with soda ash for alkaline hydrolysis of the remaining pesticides. Activated carbon was blended into the remaining lagoon bottom sludge, and a 24-mil lagoon liner was folded in half to entomb the treated residues.

Contaminated and Uncontaminated Building Materials

Personnel wearing full protective clothing carefully segregated uncontaminated building materials from contaminated building materials. These materials were staged where conventional high lifts and open bed trucks could be used to load and transport them away from the contaminated area. Consequently, only 29 yd³ of a total of 131 yd³ of contaminated and uncontaminated building materials were disposed of as hazardous wastes. Special ar-

Figure 4
Concentrated Pesticide Runoff Collected in Interceptor Pits at Burn Site.
Residues from pit 1 transferred to pit 2. Floating pump used to
transfer runoff into 17H drums by personnel wearing
full protective clothing.

rangements were made with the Illinois EPA to transport these materials in bulk containers in 24-mil polyethylene capsules, thereby minimizing packaging, transport and disposal costs.

Concentrated Leachates and Soil Matrices at Burn Site

Removal

A total of 26,675 gal of highly concentrated pesticide leachates and soil were transferred into epoxy-lined drums (Figs. 6 and 7). At this time, regulations allowed landfilling of liquids in permitted hazardous waste landfills. This method of disposal was selected to minimize disposal costs at the request of the insurance company.

At the time of this writing, the landfill to which these toxic liquid wastes were sent is now experiencing a leachate problem and will probably become the target of a future remedial action site cleanup. In retrospect, it would have been more cost-effective in the long run to have incinerated these wastes.

In Situ Detoxification

A total of 40,000 ft^3 of soils containing traces of agricultural chemicals up to depths of 3 ft were detoxified in place. Soda ash and powdered activated carbon were disced and plowed into the soil. Soda ash was applied periodically to maintain a soil pH near 9. A water mist was applied to activate the soda ash in soil.

Several physical/chemical processes were activated by this treatment: some pesticides were degraded by soda ash alkaline hydrolysis; the powdered activated carbon mitigated odors and absorbed agricultural chemicals, thereby preventing additional contaminant migration; the black carbon absorbed solar energy, thus elevating soil temperatures and catalyzing pesticide destruction; and periodic discing and aeration of soils accelerated further pesticide degradation by solar oxidation and evaporation. The site was monitored until the degradation of pesticides decreased below 0.1 mg/l.

Table 4
Final Pesticide Concentrations and Fish Bioassays Used to Confirm Decontamination below Established Yardsticks

Sample Description	Atrazine (mg/l)	Treflan (µg/l)	Dyanap (µg/l)	Furidan (mg/l)	pH	Number of Fingerlings Tested	Perch Fingerling Survival Times (hr)
Control					7.0	20	> 96
Creek prior to treatment	4.9	7.5	121.7	15	7.1	1	1.8
Treated lagoon waters	0.06	0.17	<0.5	< 0.1	6.5	5	>336
Treated creek impoundment No. 1 waters	<0.01	<0.1	<0.5	<0.1	6.7	5	>336

Figure 5
Static Bioassay Tests Run on Treated Lagoons and Stream Samples
Resulted in Perch Fingerlings Surviving the 96-hour TL_m Concentrations.

Contaminated Product Residues

A total of 500 gal of product were recovered in their original containers. Due to obvious potential third-party liability problems, these materials were not saleable and were disposed of at a hazardous waste disposal facility.

CLEANUP COSTS VERSUS LIABILITY TRADE-OFFS

The degree of decontamination accomplished should have reduced potential life safety threats and environmental impacts to acceptable limits. In the experience of the author, hazardous material cleanup costs range from 1 to 10% of potential personal injury suits and/or property damage claims. Other elements entering into the decision criteria used to determine the extent of cleanup included: available financial resources; government regulations; local media and public hazard perception; local political/regulatory interpretation of laws; and background contamination considerations.

Because of the potential multi-million-dollar liabilities associated with this incident, pesticide levels in soils and waters were decontaminated below the acceptable environmental health limits and below background concentrations typical of the watershed (Table 4).

Resources committed to this project involved around-the-clock emergency operations for 21 days and 3,200 man-hours of effort by 60 engineers, scientists and engineering technicians. Losses incurred by the owners (including chemicals, buildings and this cleanup) totalled nearly $500,000. Fortunately, all losses were insured, and the owners were reimbursed. In addition, because the site was adequately decontaminated, no legal actions have been filed.

CONCLUSIONS

Liabilities, cleanup costs and life safety hazards can be reduced by using experienced personnel with the ability to rapidly evaluate risks at hand and to select and implement engineered isolation, containment, recovery, treatment and disposal procedures. Quickly integrating the engineering investigation with an engineered solution provides a cost-effective solution to hazardous material problems.

The success of this project included: no injuries or significant impact to public health and welfare; no significant impacts to the environment; and decontamination of over 250,000 gal of contaminated surface waters using powdered activated carbon resulting in cost savings of over $180,000 when compared to the cost of using a mobile carbon treatment unit.

Utilization of natural in situ pesticide destruction processes such as photolysis and evaporation provided a cost-effective means of detoxification of pesticide-contaminated water and soils. Alkaline hydrolysis accelerated pesticide degradation in the soils and water.

Figure 6
REACT Personnel Packaging Dyanap, Treflan and White Atrazine Residues. Packaging Operations of Atrazine and Treflan Residues Using Polyethylene Bags Placed in 17H Epoxy-Lined Drums.

Fish bioassay screening of contaminated water from agricultural fire runoff afforded a pragmatic method of determining the toxicity reduction of unidentified oxidized chemicals below aquatic toxicity limits.

ACKNOWLEDGEMENTS

Figure 7
Contaminated Residues Packaged in 17H Drums. 485 Drums Were
Loaded Using Front-end Loaders and Transported by Covered Trucks
for Ultimate Disposition.

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SUPERFUND REMOVALS IN REMOTE AREAS OF THE WORLD: PACIFIC ISLAND IMMEDIATE REMOVAL PROJECT

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INTRODUCTION

Region 9 of the USEPA recently completed a Superfund immediate removal action at 39 hazardous waste sites in the Territory of Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and in the Trust Territories of the Pacific Islands (TTPI). The logistics associated with a project of this magnitude were complex and required 10 months of careful planning to overcome numerous obstacles. All site work was completed in 10 weeks at an estimated cost of $1.4 million.

Guam is an unincorporated territory of the United States under the jurisdiction of the Department of the Interior. It is also the southernmost and largest of the Mariana Islands, situated about 2,170 km south of Tokyo and 5,000 km west of Honolulu (Fig. 1). The island covers an area of 541 km² and has a total population of 105,816, including approximately 22,000 military personnel and dependents. The economy is predominantly agricultural, with a high production of fruit, vegetables, eggs, pork, beef and poultry. Fishing and tourism also constitute a large portion of Guam's economy.

The Commonwealth of the Northern Mariana Islands (CNMI), excluding Guam, is composed of 16 islands in the Western Pacific, including the three largest: Saipan, Tinian and Rota. The chief settlement, the administrative center for the commonwealth government and the government of the Trust Territories of the Pacific Islands (TTPI) are in Saipan. Saipan, the largest of these islands, has an area of 122 km² and a population of 14,885. Tinian, the second largest island, covers 83 km² and has a population of 899, while Rota covers 83 km² and has a population of 1,274. The major industry is the production of vegetables, beef and pork. Tourism also contributes to the economy of the commonwealth.

The Trust Territory of the Pacific Islands consists of the Caroline Islands and the Marshall Islands in the Western Pacific and the Mariana Islands in the Northern Pacific. The 2,185 islands, 84 of which are inhabited, are grouped into seven administrative districts (Fig. 2). The territory lies within an area known as Micronesia. The Marianas District achieved separate status as the Commonwealth of the Northern Mariana Islands and remains legally a part of the trusteeship until the Trust Territory is dissolved. The Marshall Islands District drafted its own constitution in 1979. Of the five districts of the Caroline Island group, the four districts of Yap, Truk, Ponape and Kosrae ratified a new constitution to become the Federated States of Micronesia in May, 1979.

In the seventh district, the Palau District, a referendum approved a proposed local constitution in July, 1979. It came into effect on Jan. 1, 1981, when the district became the Republic of Palau. Elections are currently being held to establish independence for the Marshall Islands, the Federated States of Micronesia (Yap, Truk, Ponape, Kosrae) and the Republic of Palau.

The total land area of TTPI is 1,300 km²; the largest islands are Babelthuap (367 km²) in the Palau District and Ponape Island (330 km²) in the Ponape District. The total population in 1980 was 116,974, distributed as follows: Marshall Islands: 31,041; Palau: 12,177; Ponape: 22,319; Truk: 31,742; Yap: 8,172; and Kosrae: 5,522. The area of the TTPI superimposed over a map of the mainland is shown in Figure 3.

The chief crops are coconuts, breadfruit, bananas, taro, yams, cocoa, pepper and some citrus. Subsistence crop production predominates and, except for copra, little is marketed.

BACKGROUND

USEPA Region 9 has had an environmental program for many years aimed at protecting the fragile environment of the Pacific Islands. The Agency gradually became aware of the uncontrolled hazardous waste sites on Guam, in the CNMI, and in Micronesia through its contacts with local government officials. Many of these sites were the subject of numerous reports and studies dating back to 1978.

USEPA contractors have surveyed hazardous waste sites in the Pacific Islands at least three times since 1978. These surveys documented numerous localized acute problems involving pesticides and PCBs, but little progress was made toward solving these problems, due to the limited resources and technical expertise of the local agencies.

In 1981, when CERCLA was implemented, the island governments hoped to obtain cleanup of all sites under the remedial provisions of the new law. The rules covering selection of individual states' highest priority sites required narrowing the scope of the remedial program to a few of the highest priority sites for inclusion on the National Priority List (NPL). Of the 32 sites originally considered for the NPL, only 11 were included on the list. The remaining sites did not score sufficiently high for inclusion. There
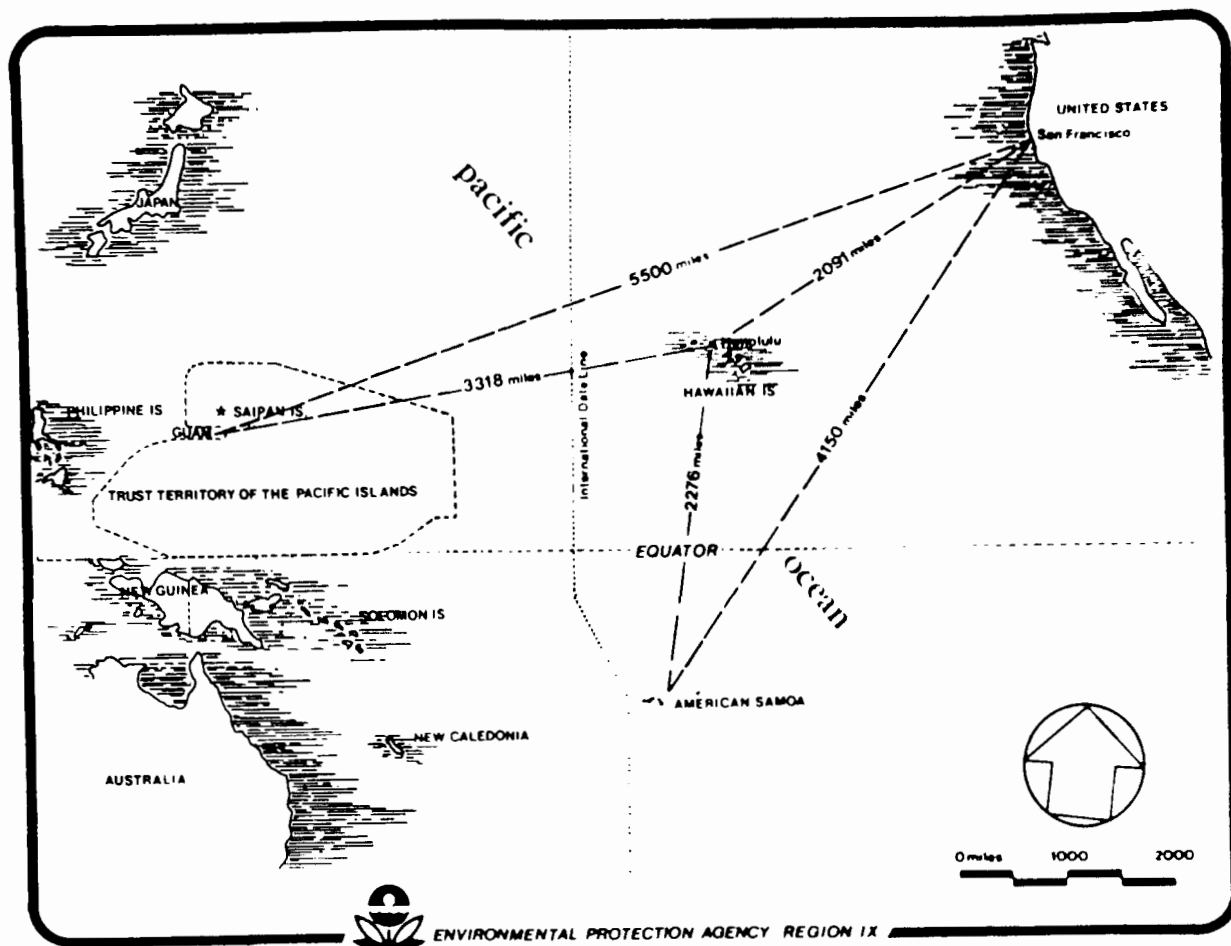
Figure 1
U.S. Environmental Protection Agency Region IX

remained, therefore, a continuing concern about the public health risk associated with the non-NPL sites.

Recognizing this, in November, 1982, Region Nine's Emergency Response Section, at the request of the Region's Office of Territorial Programs, began an evaluation of the non-NPL sites for possible planned removal action. All previous studies wered reviewed, additional inquiries were made by mail and, in March, 1983, a member of the Region Nine Technical Assistance Team (TAT) conducted a survey of these sites. At the same time, the NPL sites were surveyed for changed conditions.

There were 32 known or suspected sites on the islands of Guam, Saipan, Koror in the Republic of Palau, Moen in Truk State, Yap, Kosrae, Ponape and the islands of Jaluit, Eniwetok, Majuro and Ebeye in the Republic of the Marshall Islands. An additional seven sites were brought to the USEPA's attention upon arrival in the islands. The majority of the sites in Saipan and Micronesia were storage yards containing PCB transformers.

There were also a number of pesticide storage houses filled with deteriorating containers of banned or restricted use pesticides and some small dumps of industrial chemicals. The sites on Guam included a transformer storage yard, a hospital chemical storeroom, pesticide storage sites, a storage yard of deteriorated acid drums and storage sites of industrial chemicals.

Only a few of the sites appeared to present difficult technical problems. The staff anticipated, and were prepared to live and work under, adverse conditions. The USEPA's primary concern for the success of this removal action was logistics. In order to insure success, the USEPA had to purchase and ship all equipment and supplies overseas in advance of departure. Once on an island,

the cleanup crew had to package the waste, containerize it for shipment and make the necessary shipping arrangements for transportation to and disposal at an appropriate waste site. The problem was exacerbated by poor site access, lack of security at the sites and waterfront, substandard roads, erratic weather conditions which lead to erratic shipping schedules and the shipping requirements for incompatible wastes.

PRELIMINARY ASSESSMENT

The decision to reevaluate all of the Pacific Island sites was made late in 1982. It was immediately apparent that the available information was not adequate to evaluate current site conditions. In March, 1983, a member of the Region IX TAT conducted a Preliminary Assessment (PA) of all of the reported sites except for those on Kosrae. TAT member Erwin Koehler spent one month visiting the sites, investigating local resources and logistical support capabilities and researching potential health effects associated with these sites. The PA resulted in the following information which was used in planning the project:

• Detailed inventory of the kind and amount of waste at each site
• Analysis of the cleanup needs at each site
• Analysis of the environmental and health threats at each site
• Estimate of the number of empty drums required
• Estimate of the number of work days required on each island
• Evaluation of the logistics required on each island to ship out supplies and equipment and return drummed waste
• Evaluation of the site safety and personal protection requirements

With the PA complete, the project moved into the planning stage.
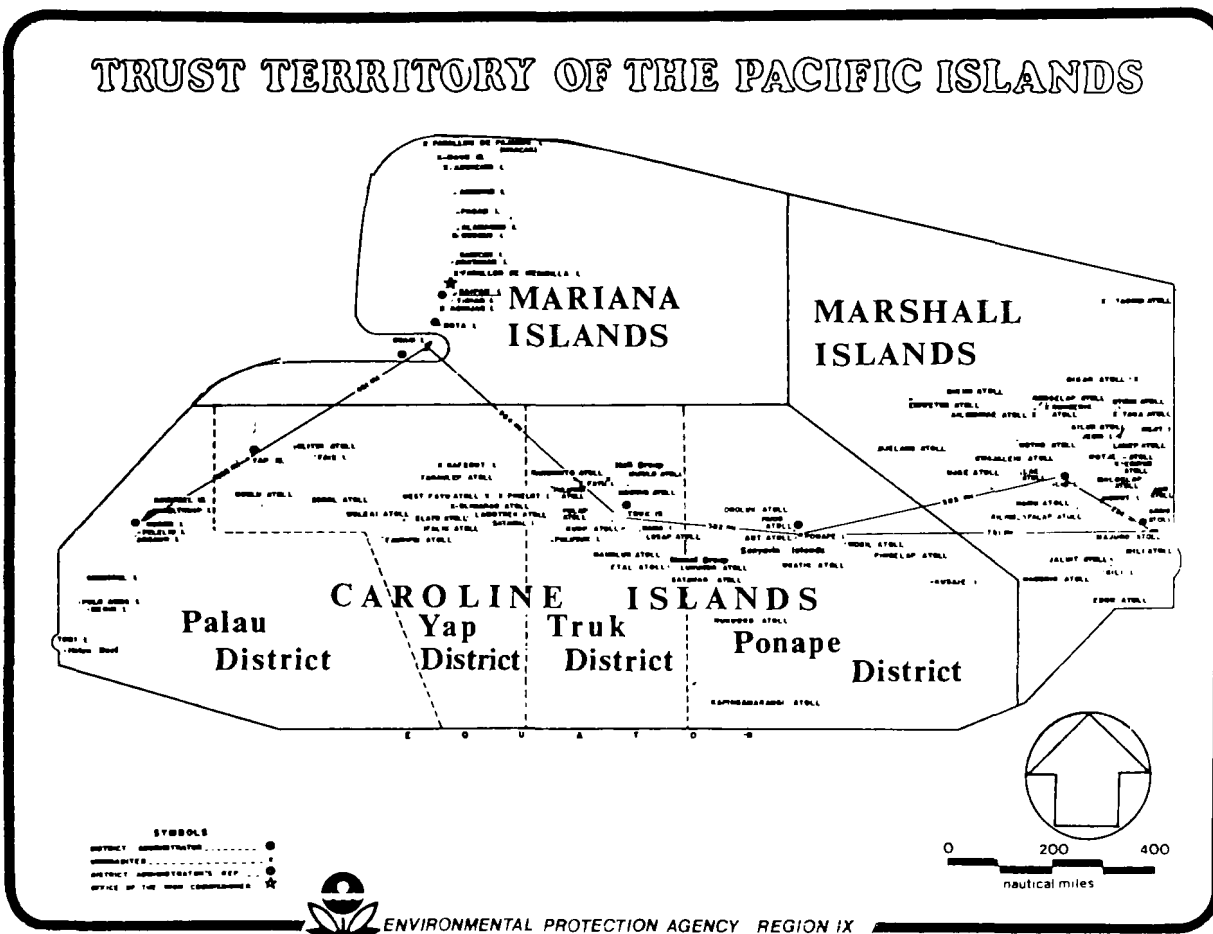
Figure 2
Trust Territory of the Pacific Islands

PLANNING

The planning for this project involved a number of tasks; principal among these were the need to:

- Reevaluate all sites and determine the number to be dealt with as immediate removals
- Prepare a funding request
- Develop a removal contract
- Resolve logistics issues
- Coordinate with local governments
- Assign personnel

The reevaluation of the 33 sites investigated during the preliminary assessment was completed in April, 1983. The TAT survey found that, in general, 32 sites qualified for planned removal action. Furthermore, several sites, including some NPL sites where conditions had deteriorated, warranted immediate removal. This information, along with the recent apparent policy change to treat planned removals as immediate removals and with the exemption from matching fund requirements enjoyed by the territories under the Omnibus Territories Act, led the USEPA to propose these actions as immediate rather than planned removals (even though some sites represented potential, rather than existing threats). It should also be noted that emergency response operations cannot be considered routine when conducted in remote areas. Public health and welfare would be best protected by removing as many potential emergency situations as possible in one sweep through the islands, minimizing the need for future responses.

A funding request was prepared and submitted in May, 1983. The initial request was for $795,000. However, at the conclusion of the planning process, the USEPA realized that it had underestimated the amount of hazardous waste to be removed and, as a result, the cost of the project. In December, 1983, an additional $602,745 was requested, thus raising the estimated project cost to $1,397,745 (Table 1).

The removal contract, developed by the USEPA headquarters Procurement and Contracts Management Division (PCMD), was unlike the usual emergency cleanup contract used by the Agency at the time. The contractor, Unitek Environmental Services, Inc. in Honolulu, HI, was hired to arrange the procurement and shipment of supplies to the islands, the shipment of waste back to the mainland and disposal. Instead of the usual time and materials contract, PCMD developed an indefinite delivery/indefinite quantity type contract with a minimum contract amount of $541,533.00 and a maximum of $1,246,445.00. The required supplies and services were ordered through the issuance of Delivery Orders by the contracting officer or the OSC's.
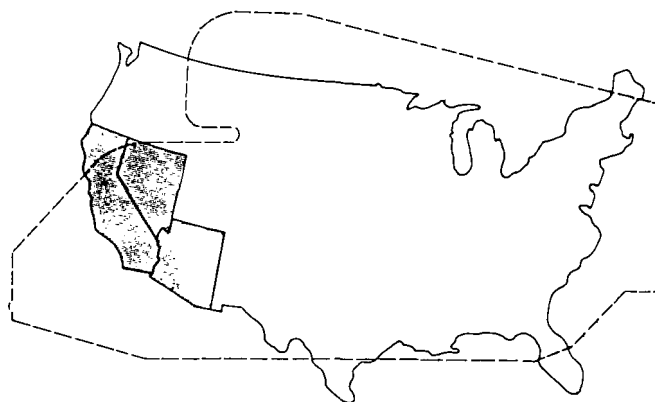
Figure 3
Area Comparison Between the U.S. and the Trust Territory of the Pacific Islands

Table 1
Estimates of Removal Costs

Item	Maximum Estimate
Personnel support:	
Government travel/per diem	$ 63,300
Government labor	$ 88,000
Contractor travel/per diem	$ 15,000
Contractor labor	$ 42,432
Materials and shipping	$ 242,935
Transportation and disposal of waste	$ 876,078
Contingency	$ 70,000
Total	$1,397,795

Table 2
Partial List of Supplies Purchased and Shipped for Use on the Pacific Islands Project

Item Description	Quantity
Digital Sphygnomanometer and Indicator	2
Electronic Thermometers w/covers	2
Centec Specific Ion Probe	4
Plastic drum liners	990
Halazone (Bottles) REI	24
Sodium Phosphate (1 lb. ea.)	26
Sodium Phosphate (500 gm ea.)	24
Mosquito Repellant (aerosol)	12
Trimethylpentane (4 per case)	2
Longhandled Decon Brush	50
Plastic Basin	50
Visquene, 6 mil x 20 ft x 100 ft	12
Spray Paint, (red) aerosol	35
Spray Paint, (yellow) aerosol	35
Spray Paint, (orange) aerosol	35
Powdered drink mix (salt replacement type)	40
55 gal drum gaskets	40
5/8 in. Bolts for Locking Rings	10
Flat Shovels	4
Pointed Shovels	2
Bug Spray	12
Sijal #896 one piece green suit	306
Charkate #6001B Tyvek Coverall	965
Edmont #34-300 Inner Gloves	72
Pioneer #AK-22 Nitrile Gloves	965
Fab Ohio #320-840 Outer Booties	965
Ranger Neoprene Steel Toe Boot	46
Duct tape, 2 in.	250
Keystone #2493T11 Drum Truck	2
McMaster-Carr #2696T1 Drum Handler	2
#3401T2 Drum Sling	2
#4239K3 Hand Pump	2
#4239K4 Repair Kit	4
#3756A3 Drum Cutter	2
#3756A4 Extra Blades	4
Hudson #7527T1 Sprayer (3 gal)	2
Emergency Medical Technician Kit	2
Mechanics Tool Kit	2
MSA #457095 Respirator (Gas Mask)	18
MSA #GMC-SS-1 Canister #77713	389
MSA #448966 Pesticide Canister	60
Vermiculite 14 lb bag, Medium Grain	150
Overpack Drum, 85 gal	160
Overpack Drum, Liner	160
Reagents for PCB Analysis (Centec)	1,100
Comealong (1 ton)	2
Drummaster #V-1-F Forklift Drum Grabber	2
Labels	1,600
Placards	150
Manifests	100
New 17E Pails (5 gal) Bung	20
Picks	2

The final contract cost would be a function of the amount and type of waste removed. Because the costs of the supplies and services had been agreed upon in the contract, the OSCs were freed of much of the paperwork associated with a time and materials contract.

As with any project located in a remote area, logistics were the most critical element for a successful operation. The plan we developed called for all of the supplies to be delivered to the USCG Pacific Strike Team in Novato, CA.

All of the supplies (Table 2) were stored in an aircraft hangar. The hangar was subdivided into spaces corresponding to each island, where the cleanup staff would be working. The supplies were then divided among all of the islands and placed in the appropriate spaces. The division of supplies was based upon a very careful evaluation of all work to be done on each island.

Items such as boots, suits, gloves, respirator canisters, etc., were packed into 55 gal drums which were then placed inside of 85 gal overpack drums. The idea was to consolidate the supplies as much as possible because shipping rates are calculated on the basis of weight or volume, whichever is most advantageous to the shipper. Once the supplies were consolidated, they were packed into containers for shipment directly to each island.

The staff considered and rejected the idea of staging supplies and equipment on Guam or Hawaii because shipments could be made directly to all the islands from the West Coast. Two steamship companies were used. Of the two carriers serving Guam, United States Lines was utilized because they were the only carrier who would return the waste to the West Coast from Guam.

Philippines Micronesia & Orient Lines (PM&O) provided direct services to Saipan and Micronesia. PM&O had no reservations about returning wastes to the West Coast. The supplies were consigned to local government officials agreeing to provide secure storage pending the USEPA's arrival.

Waste to be returned to the mainland for disposal was packed in drums and containerized for shipment back to the mainland. The amount of waste shipped off each island by hazard class is shown in Table 3.

Only one shipping related problem with the potential to disrupt the project was encountered. On the return voyage from Guam to the mainland, USL ships go via Japan. Initially, the Japanese government denied permission to ship OCB-contaminated waste through Japanese territorial waters. However, the Japanese government relented when they were advised that no containers of PCB wastes would leave the ship for any reason. Had they not relented, the USEPA would have had to forward the Guam PCB wastes to Saipan and ship them back to the mainland from there via PM&O Lines.

All of the supplies shipped to the Islands arrived in good shape. All of the waste returned to the mainland arrived without incident except for one container in which a small quantity of PCB-contaminated diesel rinsate leaked. This container was decontaminated and returned to service.

Each team had a pair of equipment boxes with tools instruments and personnel gear that was shipped from island to island by air cargo. While expensive, air cargo costs were much less than the cost of multiple sets for all of the equipment required.

Local Government

From the beginning, the USEPA intended to encourage participation by local governments to the extent of their capabilities. Each was asked to support the removal actions by providing:

- Secure storage of supplies prior to team arrival
- Certain items of heavy equipment
- Unlimited access to sites to ensure meeting time schedules
- Transportation for the team is not commercially available
- Disposal sites for non-hazardous waste
- Community relations

Table 3
Summary of Hazardous Waste Shipped for Disposal
(Does not include material which was treated or disposed of locally.)

YAP		SAIPAN	
PCB liquid	5 drums	Waste glacial acetic acid	1 drum
Waste DDT	8 drums	PCB liquid	65 drums
PCB contaminated debris	1 drum	Waste sodium arsenite	13,550 lb
PCB capacitors	1780 lb	PCB contaminated debris	2 drums
Poison B waste, lab pack	5 drums	PCB contaminated liquid	2 drums
Waste carbamate pesticide, lab pack	21 drums	Waste, poison B, lab pack	6 drums
Hazardous waste NOS, lab pack	2 drums	Waste methyl alcohol	1 drum
PCB transformers	7320 lb	Corrosive liquid waste, lab pack	1 drum
		PCB transformers	60,730 lb

PONAPE AND EBEYE		GUAM	
PCB contaminated liquid	10 drums	PCB contaminated liquid	7 drums
PCB liquid	4 drums	PCB liquid	14 drums
Waste, poison B, lab pack	2 drums	PCB contaminated debris	3 drums
PCB contaminated debris	1 drum	PCB transformers	7,550 lb
Corrosive wastes, lab pack	1 drum	PCB capacitors	3,780 lb
Waste ammonium hydroxide	5 drums	Solid hazardous waste, NOS	9 drums
Empty PCB drum	1 drum	Solid waste poison B	7 drums
Hazardous Waste NOS, lab pack	1 drum	Liquid hazardous waste, NOS	4 drums
Waste asbestos	4 drums	Waste flammable liquid, lab pack	4 drums
PCB transformers	2320 lb	Waste sodium silicofluoride	3 drums
		Waste corrosive liquid, poison B	2 drums
		Waste hydrofluorosilicic acid	17 drums
KOSRAE		Waste nitric acid, lab pack	1 drum
Contaminated debris	3 drums	Waste corrosive liquid, NOS	7 drums
PCB contaminated liquid .	20 pails	Waste calcium hypochlorite	3 drums
Waste, poison B, lab pack	5 drums	Waste oxidizer solid, NOS	2 drums
		Waste oxidizer, poison B	1 drum
		Waste formaldehyde solution	4 drums
TRUK		Waste, poison B, lab pack	27 drums
PCB contaminated liquid	12 drums	Waste corrosive liquid, lab pack	2 drums
PCB liquid	22 drums	Waste oxidizer, lab pack	1 drum
PCB contaminated debris	2 drums	MAJURO	
Empty PCB drums	7 drums	Waste DDT	9 drums
PCB transformers	19,290 lb	PCB liquid	17 drums
		PCB contaminated solids	121 drums
		PCB contaminated liquid	5 drums
PALAU		Waste, poison B, lab pack	2 drums
PCB contaminated liquid	2 drums	Waste solid, poison B	17 drums
PCB liquid	15 drums	PCB transformers	10,300 lb
Flammable liquid waste, lab pack	1 drum	PCB capacitators	150 lb
PCB transformers	8680 lb		

In the preliminary assessment, the USEPA had reviewed local government support capability. During the planning process, each island was contacted with a list of needs and a request to advise the USEPA if they could commit the requested resources or, if not, to advise the agency as to what they could provide. Two months prior to departure, all local governments were recontacted to determine if their commitments were firm. As a result of this effort, the agency received the anticipated level of support and, in a few cases, obtained more assistance than expected.

Personnel

All of the on-site work was performed by two teams made up of the USEPA, USCG and civilian contractor personnel. Each team consisted of one USEPA On-Scene Coordinator (OSC), three members of the USCG Pacific Strike Team (PST), one member of the USEPA's TAT and one employee of Unitek, the logistical support contractor.

Each team was designed to be self-sufficient. All of the team members were qualified to work in level B protection, and all were familiar with the monitoring instruments, particularly the PCB test kit. Finally, all were experienced response personnel and were familiar with hazard categorization, manifesting, site safety and decontamination procedures. Moreover, they all had worked with PCBs, pesticides and industrial chemicals in the past.

In addition to his usual duties, each OSC acted as the team leader and primary U.S. Government representative to the local government officials; he also worked on-site with the other team members. The PST supplied each team with one member who acted as the emergency medical technician (EMT) in addition to his usual duties as heavy equipment operator, diesel mechanic and/or trained responder. The TAT's primary function was to support the OSC in matters of safety and administration along with on-site work. Individual TAT members' expertise in chemistry was used in Guam several times. Unitek personnel were to handle all logistics, arrangements in the field and on-site work.

On Guam, the sites were split into two groups, and the two teams worked independently of each other. When the work on Guam was complete, the teams separated: Team A went to the Marshall Islands, Ponape and Kosrae; Team B went to Truk, Yap, Palau and Saipan.

SITE SAFETY

Personnel protection and safety was of primary concern on the project. The conditions under which the teams expected to be operating offered a greater opportunity for injury or exposure to toxic materials than any removal any member had done recently.

The risk of physical injury was enhanced because of the lack of adequate equipment and greater reliance on manpower to move drums and transformers. The lack of purified drinking water, the

lack of water for bathing and limited sanitary facilities all had the potential to result in debilitating illness.

Perhaps the most serious health threat encountered on a daily basis was heat stress. Despite the efforts of the EMTs to monitor team members, everyone suffered the effects of heat stress on more than one occasion, and one team member was incapacitated due to dehydration. The team attempted to minimize the potential for heat stress by working at night and carefully monitoring each individual before, during and after work.

Prior to departing from the mainland, the TAT had prepared a site safety plan for each of the sites. The plans were reviewed upon arrival in order to incorporate changes in site or working conditions. One such modification, introduced on Guam and used for the duration of the project, was the modification of the decontamination procedure to eliminate the use of washdown water as much as possible. Washdown was limited to the SCBA bottle and harness and to emergency situations involving gross accidential contamination. The so-called "dry decon" consisted primarily of discarding all external protective clothing after each site entry.

FIELD TESTING

The Guam EPA had moderate analytical laboratory capability. Essentially, there were no other laboratory capabilities in the Trust Territories. Therefore, it was necessary to do as much material characterization in the field as possible to avoid long delays in determining what handling, shipping and disposal techniques were required. There are basic hazardous categorization tests which are done on any waste site (i.e., pH, flammability and general identification of physical properties). These tests alone would not have been sufficient for the Pacific Islands Project.

Having team members with extensive chemical backgrounds was very useful. This enabled the team to sort hundreds of bottles of waste laboratory chemicals into the proper hazard classes using label identification. The team was also able to identify an unmarked drum of an unknown material (Freon) and to test a white powder identified only as "Miracle" to determine whether it was a pesticide or a cleaning compound. This task was done with a small amount of laboratory equipment and a knowledge of the physical and chemical properties of the materials involved.

In another case, volumetric analysis was used to determine the strength of waste acids and eliminate concern that the acid in open topped drums had stratified (stratified acid presents a hazard if heat is generated when the acid is mixed during recovery).

The team's most useful piece of field test equipment was a Centec PCB test kit which measures PCBs by causing the release of a chloride ion which, in turn, is detected by a specific ion electrode. Use of the test kit allowed the quantitative categorization of transformers, capacitors, transformer oil and soil into one of three categories: non-PCB, PCB-contaminated and PCB (less than 50 ppm, greater than 50 ppm but less than 500 ppm and greater than 500 ppm, respectively). The team was also able to determine the extent of PCB soil contamination.

The kits performed very well, needing only replacement of batteries and, in one case, the specific ion probe. They operated better in a cool hotel room than outside, where the temperature was 85°-87°F and the humidity was close to 90 percent. The real problem involved reagents: hexane evaporated during shipment from the mainland necessitated development of a calibration curve using 2,2,4 trimethylpentane as a substitute.

DISPOSAL OPTIONS

The largest expense associated with the removal actions was the shipment and disposal of hazardous wastes. There are no RCRA-permitted hazardous waste sites anywhere in Micronesia, so alternatives to disposal in a mainland hazardous waste site were very limited. The options considered were:
●Incineration
●Neutralization
●Recycle/reuse
●Explosive destruction
●Landfill

Incineration was used to dispose of transformer oil with a PCB content of less than 50 ppm. The oil was mixed in a 1 to 5 ratio with diesel oil and used for fuel in the local power plants. Over 200 drums of oil were disposed of in this manner. Shipment and disposal on the mainland would have colst about $550 per drum, so an estimated $110,000 was saved.

Neutralization of waste acid had been proposed at 2 sites. In one case, the acid was being used so there was no need to remove or neutralize it. In the other case, the USEPA proposed to neutralize 900 gal of what was supposed to be rainwater contaminated by hydrofluorosilicic acid. After testing the material, the team found it to have a pH of near 0 and a normality of 4 to 6. Neutralization was abandoned because the acid was significantly stronger than expected, and the OSC felt that a neutralization reaction could result in the formation of a vapor cloud which could potentially affect nearby residents.

Reuse or recycling of hazardous materials was only practical on Guam. Here, the team was able to recover two drums of caustic soda and give them to a local chlorine bleach manufacturer. Many of the "waste" laboratory reagents removed from laboratory chemical store rooms were found to be of value and were returned to the clinical laboratory for use.

Some of the waste sites yielded highly reactive materials such as picric acid, white phosphorous, metallic sodium, ether and/or non-shippable containers of compressed gases. On Guam, these materials were turned over to a Navy Explosive Ordinance Disposal Team who safely destroyed them at an explosives range. On Yap, a number of containers of picric acid were destroyed by gunfire in a remote area of the island.

The original plan called for all the waste to go to a single disposal site. The shipping containers full of drummed waste would be unloaded from the ship, placed on trucks and taken directly to the disposal site. However, the site proposed by the USEPA advised the agency they could no longer take RCRA wastes, only PCBs. As a result, a substantial amount of the waste had to be recontainerized. Ultimately RCRA wastes were sent to four sites in addition to the one which took the PCBs. The delays resulting from recontainerizing exceeded 96 hours, therefore requiring the team to get temporary TSD permits issued to the transporter.

FIELD OPERATIONS

It is beyond the scope of this paper to describe in detail the actions taken at all of the sites. A listing of the sites, and the types of waste materials removed, is found in table 4. With few exceptions, the sites were either pesticide/chemical storage areas or transformer storage yards. However, detailed descriptions of operations at two sites, good examples of the degree of flexibility required in a project of this complexity, follow this section.

The team used the same basic approach to all of the transformer storage sites:
●Clear vegetation and debris from around transformers
●Clear a staging area if necessary
●Stage and number all transformers
●Open and sample all transformers for analysis
●Pump transformers with PCB concentrations between 50-500 ppm
●Pump transformers with PCB concentrations greater than 500 ppm and fill with diesel oil
●Pump contaminated diesel oil and rinse
●Pump transformers with PCB concentrations less than 50 ppm
●Prepare PCB transformers for shipment by partially filling with vermiculite, resealing the lid, wiping down the exterior and collecting information off the data plate
●Load containers

The team used either an electric or gasoline driven pump, reinforced garden hose and a stinger fabricated from PVC water pipe to drain transformers. Some of the larger transformers were drained by connecting the pump to the drain valve on the bottom. The transformers shipped back to the mainland ranged in size and volume from 110 lb, 10 gal capacity to 30,000 lb 1500 gal capacity.

Table 4
Pacific Islands Project: Site Inventory

Site/Location	Disposition
Guam	
1 Univ Guam Pest. site	Completed 2/29
2 Univ Guam Ag Exp Stn	Completed 2/29
3 Guam Mem Hosp lab	Completed 3/1
4 PUAG Acid Waste site	Completed 3/7
5 Dept of Ag Pest. site	Completed 3/6
6 Baza Gardens drum site	Assess 3/8: No hazmat found
7 GEDA site	Completed 3/1
8 DPHSS Pest. site	Completed 3/2
9 DPHSS Lab	Completed 3/7
10 Perez Bros drum site	RP cleanup 3/13
11 Harmon Plaza site	Completed 3/1
12 Connell Bros drum site	RP cleanup 2/29
13 GPA/Naval Stn PCB storage	Completed 3/13
A Dept of Ed lab	Completed 2/29; no funds req'd
B delaCruz drum site	Completed 3/8; funding $20K approved
Saipan	
14 CNMI PCB site	Completed 4/29
15 CNMI TTPI warehouse site	Completed 4/29
Palau	
16 DPW PCB site	Completed 4/20
Majuro	
17 PCB site	Completed 3/27
18 Dept of Ag site	Completed 3/26
19 DPW PCB site	Completed 3/23
20 DDT site	Completed 3/23
24 DPW old plant site	Assess 3/27: No hazmat found
C Hospital lab	Completed 3/22; no funds req'd
Ebeye	
21 DPW PCB site	Completed 4/4
Eniwetok	
22 DPW PCB site	DOE cleanup: No response req'd
Jaluit	
23 DPW PCB site	Material moved: No resp. req'd
Ponape	
25 Electric shop	Completed 4/14
26 Nett Rd site	Completed 4/14
27 Dept of Forestry site	Completed 4/14
28 Gov't warehouse	Completed 4/14
Kosrae	
29 DPW PCB site	Completed 4/13
Truk	
30 DPW PCB site	Completed 3/31
31 Military dump site	Assess 3/31: No hazmat found
Yap	
32 DPW PCB/pest. site	Completed 4/11
F Pesticide site	Completed 4/11; funding $13K approved
G USCG PCB storage	Completed 4/11; no funds req'd
Ejit	
D Med Clinic pest. site	Completed 3/24; funding $10K approved
Kwajalein	
E Army PCB storage	Tech assist to RP only

28 CERCLA funded cleanups (25 from orig. project + 3 new funded sites B, D, F)
3 RP cleanups (Sites 10, 12, E)
3 USEPA cleanup, no funds required (Sites A, C, G)
5 5 Sites where no action required (Sites 6, 22, 23, 24, 31)

39 Total sites

All of the pumping operations involving PCB or PCB-contaminated oil or diesel oil were conducted by staff in Level C protective gear.

The chemical storage/pesticide storage sites were cleaned up using one basic procedure. The work was conducted by a crew of three or four persons in either Level C or B protection. In all cases, the materials were inside laboratory storerooms or other confined spaces too small for a crew of three or four to work effectively.

At each site, the team set up a bench in front of the storage area. Drums which would receive the waste were lined up on one side of this bench. One crew member removed waste materials from the storage area and brought them out to the bench. A second crew member recorded the chemical name or, if a pesticide, the active ingredients of every container and verified the hazard class. The remaining crew members placed the materials in a drum labeled for the appropriate hazard class. Once all the materials were removed from the storage area, the interior spaces were decontaminated with chlorine bleach or TSP.

One must record the chemical name or pesticide active ingredients when making up a "lab pack," because hazardous waste disposal sites may not accept "lab packs" without it.

PUBLIC UTILITY AGENCY OF GUAM ACID WASTE SITE

The Public Utility Agency of Guam (PUAG) acid waste site located in Dededo, contained an estimated 200 15 gal polyethylene lined drums of hydrofluorosilicic acid. The drums were highly deteriorated. They all had cracked liners, and many had spilled all or part of their contents onto the surrounding soil. Additional waste materials on this site included approximately 1000 lb of sodium silicon fluoride and quantities of assorted shelf chemicals.

The original cleanup plan for this site called for the on-site neutralization of the acid using locally available coral sand. This plan was based on the assumption that, since the containers had been exposed to the rainy tropical environment for several years, the contents would have been diluted considerably. This plan was abandoned when field testing indicated that the acid had a pH of near 0 and a concentration of 4 to 6 n. The neutralization of such a large quantity of strong acid on-site could cause many problems.

The revised cleanup plan required the pumping of all acid into polyethylene drums which had to be obtained locally. The empty containers were neutralized with a small quantity of coral sand and disposed of at a local land fill dump. The contaminated soil was covered with clean coral sand. The other materials on-site were segregated into compatibility groups and packaged in 55 gal open head drums. Decontamination water and water used for cooling personnel on this site was treated by filtration through a coral sand berm.

EJIT ISLAND PESTICIDE STORAGE SITE

During the early stages of cleanup actions on Majuro, the USEPA was informed of the existence of a pesticide storage site located on a neighboring island within the atoll. Ejit Island, located a short boat ride to the northeast of Majuro, presently serves as a relocation home for many of the former residents of Bikini Island. The island has no roads, no electricity and no water or sewage systems. Upon arrival on the island, the OSC determined that the pesticide storage room occupied the middle room of a small building; one end was a one-room schoolhouse, and the other end was a part time medical clinic. The 20 ft x 20 ft pesticide storage room was grossly contaminated by hundreds of bags of pesticides in a highly deteriorated state.

The cleanup of this site presented an unusual logistical problem since the island is not serviced by a commercial shipping line. In order to ship empty drums, safety equipment and other supplies to Ejit, it was necessary to charter the services of a 16 ft aluminum boat. Three round trips were required to transport the supplies and the three man cleanup crew.

The cleanup operation at the site required an entry team using Level C protection and entailed the removal and containerization of all pesticides followed by a chlorine bleach scrubbing of all interior surfaces of the storeroom. Upon completion of the removal action, the team found that the filled drums of wastes were too heavy to be transported in the small boat. Arrangements were made with the Marshallese Government which was able to provide an old military landing craft (LCU) to transport waste from Ejit to the Port of Majuro.

CONCLUSIONS

With completion of the Pacific Islands Project, Region 9 USEPA successfully removed all of the hazardous waste it originally set out to remove, as well as additional waste brought to its attention during the project. The project was also successful in meeting time and budgetary goals. There are many factors which made this complex project a success. The most important are:

•The investment of time into conducting a thorough preliminary assessment, particularly where there was a lack of local capability to recognize, assess and solve the problems associated with hazardous wastes.

•The extensive planning and front-end logistics effort which insured that the supplies and equipment were delivered on time, in good condition and at the proper location. The prompt removal and safe transportation of the wastes to a disposal site was also assured.

•The use of multi-disciplinary teams set up to be self-sufficient. They were given the flexibility and authority to deal with unexpected situations which arose while in the field.

•The establishment and maintenance of good liaison with the local governments involved. The valuable cooperation and support received might not have been provided without the established good working relationship.

REMEDIAL INVESTIGATION AND FEASIBILITY STUDY FOR THE POLLUTION ABATEMENT SERVICES SITE (OSWEGO, NEW YORK)

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INTRODUCTION

The 15.6-acre Pollution Abatement Services, Inc. (PAS) site is located near the eastern limit of the City of Oswego, New York, approximately 2000 ft south of Lake Ontario (Fig. 1). It lies within a light commercial zone and is bounded on its south by East Seneca Street and on its remaining three sides by a designated wetland formed along the stream channels of White and Wine Creeks. Adjacent properties include a residence on the north, union hall on the east, solid waste transfer station (formerly the Oswego County Landfill) on the south and radio station on the west.

From 1970 through 1977, PAS was operated as a high-temperature liquid chemical waste incinerator facility. Throughout its active life, the facility experienced continuous operating problems, numerous air and water quality violations and mounting public opposition. During this time, a large number of drums containing various chemical wastes were collected and stored on-site, as were liquid chemical wastes in several on-site lagoons. In 1977, PAS was abandoned. It was subsequently listed among the top 10 priority sites on USEPA's initial National Priorities List.

During the several years immediately following its abandonment, a number of emergency remedial actions were taken at the site to limit access, contain hazardous materials and remove some of the chemical waste products. During the summer of 1982, a major surficial cleanup of the site was undertaken, which included the demolition and disposal of on-site facilities and the removal of approximately 8,000 drums and 80,000 gal of liquid chemical wastes. Immediately following this surficial cleanup, the present study of PAS was commenced.

The primary purpose of this study was to conduct a complete and thorough site investigation in order to identify continuing sources of contamination (especially subsurface sources); to define the existing geological, hydrological and hydrogeological conditions at the site; to identify the vertical and horizontal extent of contaminant migration; to assess the present and potential impact of the site upon the environment and human health; and to identify and evaluate feasible remedial alternatives.

Figure 1
Location Map

REMEDIAL INVESTIGATION

Study Methods

The following study methods were utilized to develop a site characterization upon which the subsequent development and evaluation of remedial alternatives were based:
• Review and evaluation of existing data and information concerning the site at the outset of the study
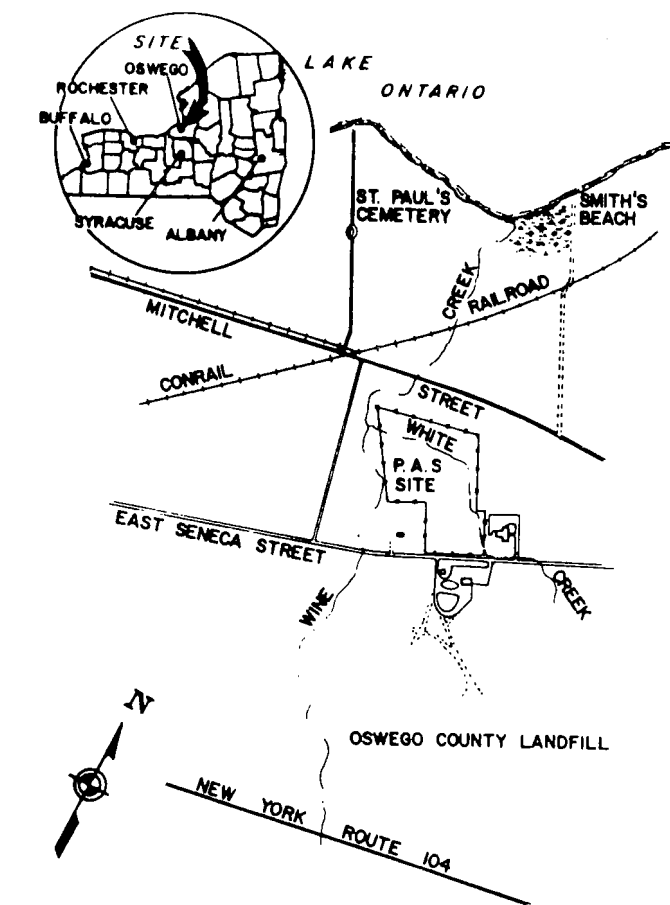
• Development of Comprehensive Health/Safety and Quality Assurance/Quality Control Plans prior to the initiation of on-site activities
• Development of expanded site base map with updated topography
• Performance of detailed geophysical studies of the site and surrounding area using the techniques of terrain conductivity, electrical resistivity and seismic refraction

- Collection and analysis of surface water and stream sediment samples from stations along White and Wine Creeks
- Installation of backhoe test pits and trenches, soil borings and groundwater monitoring wells on-site and in the surrounding area; performance of geophysical well logging and in situ permeability testing during the installation of the borings; performance of slug tests in the monitoring wells after they had been developed and allowed to recover
- Performance of soil screening tests for total volatile organic compounds (VOC) and polychlorinated biphenyls (PCBs) using a mobile laboratory on-site during the installation of test pits, trenches and borings
- Collection of soil samples from the test pits, trenches, borings and monitoring wells for detailed laboratory analyses
- Collection of groundwater samples from each of the monitoring wells for detailed laboratory analyses
- Performance of follow-up detailed electrical resistivity survey in an area of the site which, on the basis of field investigation results, exhibited anomalous behavior
- Performance of preliminary aquatic and biological survey upstream and downstream from the PAS site along White and Wine Creeks

Site Characterization

The data obtained during the field investigation were collectively analyzed to form an overall understanding of the PAS site and its impact upon the surrounding area. This site characterization, as it relates to potential remedial actions, is summarized in the following paragraphs.

The most important environmental feature of the PAS site is the wetland which borders the (approximately 7-acre) former active area of the site along White and Wine Creeks and extends northward from the site along Wine Creek to Lake Ontario. A variety of fauna make use of the wetland area, including a wide variety of avian species. Also, a number of fish species appear to migrate up White and Wine Creeks as far as the PAS site during the spring spawning season. Almost all of the surface water flow from PAS drains toward White Creek on the north and east. The drainage area of this stream measures approximately 1340 acres upgradient from PAS and increases by approximately 2% as it passes through the site.

The site is located in a fairly complex geological setting characterized by glacial deposition and reworking. Six stratigraphic units were encountered during the subsurface investigation, including a surficial layer of fill material deposited on the site prior to the construction of PAS. The two most important stratigraphic features of the site are: (1) a dense, continuous lodgement till layer which underlies the more permeable surficial soils; and (2) a depression in the central area of the site which contains stratified sediments to greater depths than found elsewhere on-site. The site is underlain by sandstone bedrock with low intrinsic permeability at depths which range from approximately 30 to 50 ft.

Separate groundwater flow systems were observed in the overburden soils, down to lodgement till and in the underlying bedrock. The upper, unconfined flow system has a water table configuration which closely reflects surface topography. The water table gradient in this system ranges from around 0.02 to 0.13 and slopes generally northward toward Lake Ontario. The bedrock piezometric surface is lower than the overburden water table and also flows northward with a gradient of approximately 0.004 to 0.007. Consideration of the water table configuration and stratigraphy of the site leads to the conclusion that White and Wine Creeks are effluent in nature and that these streams act as hydraulic barriers which intercept groundwater flow through the surficial soils at PAS. This, in turn, leads to the secondary (and most important) conclusion that surface water, particularly White Creek, is the most likely pathway for contaminant migration off-site. This conclusion is supported by surface geophysical studies, which detected no groundwater contaminant plume passing under White or Wine Creek from the PAS site and by groundwater analytical data, which indicated that con-

taminants found in groundwater underlying the site are generally absent on the opposite side of White Creek.

Surface water analytical data indicate high levels of contamination in the two on-site drainage ditches at PAS and detectable but show relatively low and non-persistent effects of PAS upon downgradient water quality. However, the actual impact may have been obscured to some degree by the short, winter sampling period and by the filtering effect of the marsh adjacent to the site. A subsequent spring aquatic survey of White and Wine Creeks indicated that they are severely stressed at and downstream from the PAS site.

The soils and groundwater underlying PAS are highly contaminated by a wide variety of priority pollutants. Although these subsurface contaminants are distributed nonuniformly across the site, a number of the most highly contaminated samples are located near former chemical waste processing and storage areas such as the lagoons, drum piles and buried subsurface tanks. Furthermore, soil screening results clearly indicate that soil contamination generally decreases with depth, with most of the observed contamination occurring within the upper 10 ft of the soil. PCB-1248 was detected at relatively high concentrations in the area of the site to the north and west of the former drum loading platform (Fig. 2). This fact, plus the visual observations of a black, oily substance leaking from the dumping bin behind the former loading platform (Fig. 3), breaking out at the toe of slope downgradient from the platform (Fig. 4) and breaking out on the ground surface above subsurface Tank No. 9 (Fig. 5), indicate that there is an active source (or sources) of PCB-contaminated liquid leaking into the subsurface in this area of the site.

The primary potential impact of the PAS site appears to be upon surface-water-related activities at and downgradient from the site. Groundwater resources north (downgradient) of PAS are little used at present, with public water available throughout the area, and have little chance of being further developed since much of th area
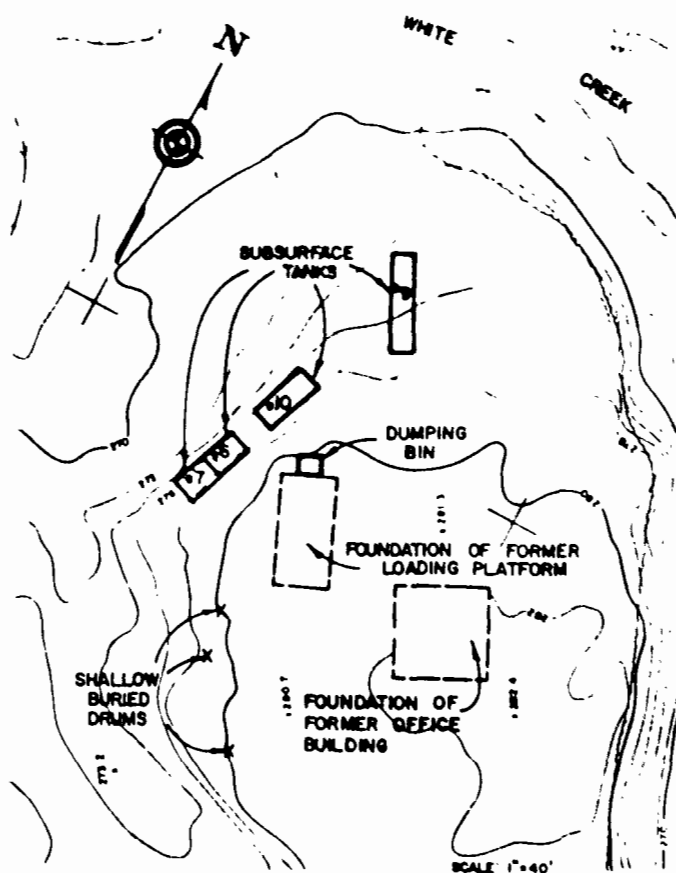
Figure 2
Existing Subsurface Tank and Drum Locations

Figure 3
Dumping Bin Behind Former Loading Platform

Figure 4
Contaminant Breakout Below Former Loading Platform

Figure 5
Contaminant Breakout Above Subsurface Tank No. 9

north of PAS is undevelopable. Surface water, on the other hand, is used not only by fauna inhabiting and migrating through the wetland area, but also by fishermen on a seasonal basis.

The off-site property most directly affected by conditions or future activities at PAS is the adjacent radio station; it receives contaminated surface runoff from the site, a portion of which will have to be included in any regrading and capping of PAS. Consideration was also given to the potential impact which the adjacent Oswego County Landfill (OCL) might have upon the PAS site. Although the OCL is upgradient from, and in direct hydraulic contact with PAS, the quality of surface water and groundwater at the two sites are distinctly different, with no evidence of hazardous contaminants originating from the OCL.

EVALUATION OF REMEDIAL ACTIVITIES

Methodology

Initially, individual remedial measures considered practical at the site were identified and expanded specifically for application at PAS. Next, these individual measures were incorporated, in various combinations, into six alternative remedial plans. Each of the plans was rated using a weighted matrix system which "scored" the plans on the basis of four categories: level of cleanup, reliability, longevity and operation/maintenance requirements. The cost of each alternative was computed as a basis for comparison, although the final selection of a remedial alternative was based primarily upon its overall effectiveness.

Identification of Individual Measures

Initially, the "universe" of potential remedial measures at hazardous waste sites was narrowed for specific application to PAS on the basis of technological, practical and preliminary cost considerations. Conceptual designs and preliminary cost estimate were developed for each of the individual measures which survived this screening process. A conceptual design and cost estimate, respectively, for one of the measures which is considered to be feasible at PAS—a shallow leachate collection system—are shown in Figure 6 and Table 1. In all, the following measures were considered:

- *Limited Excavation and Removal*—Although wholesale removal of all contaminated soil from the site was not considered to be practical, the excavation and removal of the remaining subsurface drums and storage tanks (Fig. 2) was evaluated.
- *Grading and Capping*—The poor surface drainage and permeable nature of the soil cover at PAS suggest the benefits of regrading and capping the site. The following capping/cover systems were initially considered: layered soil covers, bentonite admixtures and membrane liners. At this site, combined effectiveness and cost considerations led to the selection of a 50-mil high density polyethylene (HDPE) membrane cap.
- *Stream Diversion*—The existing topography and drainage characteristics at PAS would permit the rerouting of White Creek, which presently flows adjacent to and collects leachate from the most contaminated areas of the site. The option of diverting this stream to Wine Creek via a 60-in. diameter conduit, approximately 1,000 ft in length, was considered.

•*Slurry Trenching*—The construction of a slurry wall was evaluated from two aspects—as a perimeter wall for containment of contaminated groundwater and as an upgradient groundwater diversion. The perimeter containment wall, extending over approximately 0.5 mile to an average depth of 14 ft, was considered to be most practical and was carried forward in the evaluation process.

•*Leachate Collection*—Collection of shallow leachate, via a series of collection drains discharging to a duplex pump station and thence to an existing on-site storage tank, was evaluated (Fig. 6 and Table 1).

•*Groundwater Recovery*—An existing stratigraphic depression, containing highly contaminated sediments, is located near the center of the site. Groundwater recovery from this depression was evaluated, again using the existing on-site tank for temporary storage prior to leachate disposal.

•*Leachate Disposal*—Two methods of leachate disposal were considered—on-site treatment and off-site removal for treatment by a private facility. The anticipated quantity of leachate to be disposed of led to the selection of on-site treatment. Based upon analytical results obtained during the study, but pending a bench-scale treatability study, a treatment process consisting of flow equalization, precipitation/flocculation/sedimentation, activated carbon adsorption and neutralization was preliminarily selected.

•*Miscellaneous Items*—In addition to the previous list, several miscellaneous, non-construction measures were evaluated. These include a detailed environmental assessment of the stream/wetland system downgradient from PAS and various regulatory actions. Since contamination from the site is continuing, a progressive remedial program is warranted, with the initial step being to control the source of contamination through implementation of (some combination of) the remedial measures listed above. The purpose of an environmental assessment would be to determine whether additional off-site corrective measures will be required at a later date. The regulatory actions evaluated include: requiring disconnection of the few remaining drinking wells downgradient from PAS and connection to the already-available public water system; institution of a temporary fishing ban for the stream downgradient from the site; and placement of a temporary moratorium on new development in a small area immediately adjacent to the Smith's Beach marsh (Fig. 1). The latter two regulatory actions would be temporary, pending the outcome of the environmenal assessment. Furthermore, disconnection of the potable water wells is considered to be conservative and precautionary since there is no evidence at present to indicate contamination of these downgradient wells.

Table 1
Cost Estimate for Leachate Collection

DESCRIPTION	COST
Capital Costs	
Leachate Drain (430 ft, installed, including perforated PVC, stone filter and filter fabric wrapping)	$ 3,100
Leachate Collectors (850 ft)	$ 9,300
Pump Station (installed, including stainless steel duplex unit, 72-in. fiberglass basin, controls and electrical service)	38,800
Forcemain (420 ft., installed, 2.5 in PVC)	1,400
Subtotal/Estimated Construction Costs	$52,600
Engineering/Legal/Administrative (15%)	7,900
Contingency (20%)	10,500
Total Estimated Capital Cost	$71,000
Operation and Maintenance Costs (Annual)	
Labor and Materials	300
Electricity	50
TOTAL ANNUAL O&M COSTS	$ 350
Present Worth of O&M Costs (5 yrs., 7 5/8%)	1,400
TOTAL PRESENT WORTH	$72,400
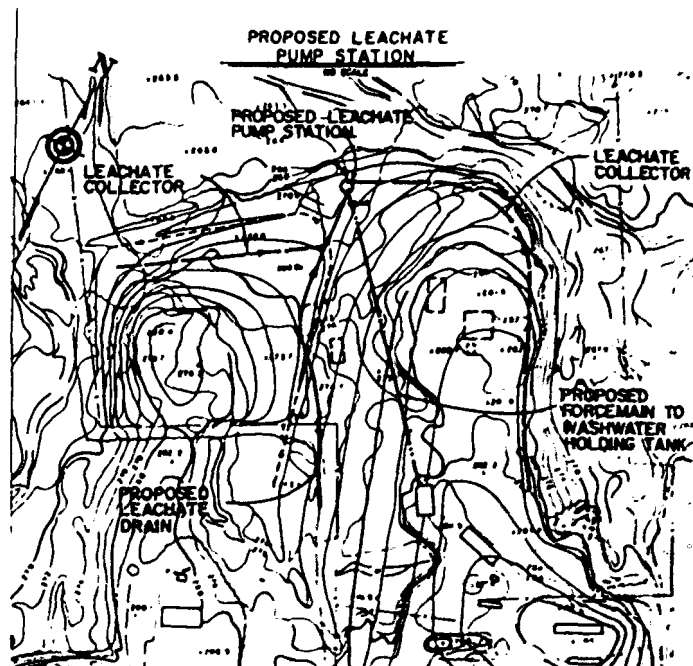
Figure 6
Conceptual Leachate Collection Plan

Development and Evaluation of Remedial Alternatives

Of the individual remedial measures discussed in the previous section, some are independent of each other, some are complimentary and others are mutually exclusive. These functional relationships were used to incorporate the individual measures, in various combinations, into six alternative remedial plans. The plans are identified in Table 2.

Following plan development, a system was developed and utilized to evaluate the relative effectiveness of the plans. This evaluation procedure consists of a weighted matrix with each alternative rated individually in the following four categories:

•Level of Cleanup
•Reliability
•Longevity
•Operation and Maintenance Requirements

The categories are scored independently on a "1 to 5" scale, with "1" representing the lowest (or worst) score and "5" representing the highest (or best). The independence of the scoring system is important. For example, an alternative which initially provides a high level of cleanup but has a limited or uncertain life expectancy would score high in the former category but low in terms of "longevity." The weights of the various categories are also assigned independently and partially reflect the attitudes and preferences which had been expressed by local officials, regulatory agencies and the general public.

The scoring system developed and used in this study is only semi-quantitative. Unlike costs, the incremental benefits of alternative plans cannot be quantified on an absolute basis. Rather, the scoring system provides a relative basis for comparison. Although costs have been calculated for each of the alternative plans, primary emphasis in the evaluation procedure has been placed upon their relative effectiveness. The scoring of the six alternative remedial plans evaluated at PAS is given in Table 3.

Recommendations

Alternative No. 1 is the most effective and the most costly of the six plans evaluated (Table 2). However, the other remedial measures (e.g., excavation and removal of the entire contaminated surficial soil layer) are more expensive than Alternative No. 1, but

Table 2
Alternative Remedial Plans for the PAS Site

Alternative	Components
Alternative No. 1	Limited Excavation and Removal
	Grading and Capping
	Perimeter Slurry Wall to Lodgement Till
	Leachate Collection
	Groundwater Recovery
	On-site Treatment
	Miscellaneous Items
Alternative No. 2	Limited Excavation and Removal
	Grading and Capping
	Stream Diversion
	Leachate Collection
	Groundwater Recovery
	On-site Treatment
	Miscellaneous Items
Alternative No. 3	Limited Excavation and Removal
	Grading and Capping
	Stream Diversion
	Leachate Collection
	On-site Treatment
	Miscellaneous Items
Alternative No. 4	Limited Excavation and Removal
	Grading and Capping
	Stream Diversion
	Miscellaneous Items
Alternative No. 5	Limited Excavation and Removal
	Grading and Capping
	Perimeter Slurry Wall to Lodgement Till
	Miscellaneous Items
Alternative No. 6	Limited Excavation and Removal
	Grading and Capping
	Miscellaneous Items

Table 3
Evaluation of Alternative Remedial Plans

	Alternative Nos.					
	1	2	3	4	5	6
Level of Cleanup (Weight = 3)						
Category score	5	5	4	3	3	1
Weighted score	15	15	12	9	9	3
Reliability (Weight = 1)						
Category score	4	3	4	3	4	3
Weighted score	4	3	4	3	4	3
Longevity (Weight = 1)						
Category score	3	3	3	3	3	4
Weighted score	3	3	3	3	3	4
O&M Requirements (Weight = 1)						
Category score	2	2	4	5	5	5
Weighted score	2	2	4	5	5	5
Total Weighted Score	24	23	23	20	21	15
Total Estimated Cost ($ × 10³)	2,281.9	2,166.9	2,050.7	1,442.0	1,557.0	1,219.5

were eliminated during the preliminary screening process for one or more of the reasons mentioned in the evaluation section. Alternative No . 1 alone provides a containment slurry wall and groundwater recovery system, thereby addressing the possibility of a groundwater contaminant migration pathway from the stratigraphic depression in the central area of the site. Although the remedial investigation did not indicate the presence of such a pathway, its existence could not be ruled out. On this basis, and pursuant to conversations with the New York State Department of Environmental Conservation and the USEPA, Alternative No. 1 was recommended. In summary, this recommended alternative includes the following measures: limited excavation and removal of subsurface tanks and drums; construction of a perimeter slurry wall around the site; construction of a shallow leachate collection system; installation of a groundwater recovery system; construction of an on-site treatment facility; grading and capping of the site; and performance of an off-site study and institution of various regulatory actions.

The recommended remedial plan for PAS will cost an estimated $2.28 million (total including additional study, design and construction) and require approximately 68 weeks to fully implement. Permits will be required for wetland disturbance and discharge from the on-site treatment plant. A long-term baseline and post-closure monitoring program has been recommended to accompany the plan.

CASE STUDIES INVOLVING THE TREATMENT OF HAZARDOUS SUBSTANCES UNDER THE SUPERFUND REMEDIAL ACTION PROGRAM

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INTRODUCTION

The USEPA began the Superfund cleanup program after passage of CERCLA in 1980. The Superfund program operates under the guidelines of the National Contingency Plan (NCP), which was published on July 16, 1982. This plan was expanded by the USEPA to provide new Federal authority to respond to the problems at abandoned or uncontrolled hazardous waste disposal sites. The NCP outlines three categories of response actions: immediate removals, planned removals and remedial response actions.

Remedial response actions are intended to achieve solutions consistent with permanent remedy at uncontrolled hazardous waste disposal sites. As such, more time and effort are required to determine the "appropriate extent of remedy—the least expensive remedy that is technologically feasible and reliable, effectively reduces the danger and adequately protects public health, welfare, and the environment". The NCP identifies three types of remedial response actions which are based upon the complexity, immediacy and extent of the hazards: (1) initial remedial measures, (2) source-control and (3) off-site remedial actions.

Initial remedial measures are appropriate when the actions to be taken are limited in nature and require a minimum of planning. The source-control and off-site remedial actions are more complex and require more extensive engineering evaluations to select the most cost-effective solutions.

An initial remedial measure is being implemented at the Bridgeport Rental and Oil Services (BROS) site in New Jersey involving the treatment and disposal of the aqueous phase of an 11.8-acre lagoon. Source-control remedial action is being implemented at the Sylvester site in New Hampshire in two phases. The first phase involved the installation of a slurry wall and cap. The second phase will include the extraction and treatment of highly contaminated groundwater within the containment system. The planning activities and engineering studies leading up to the selection of the treatment systems at these two sites are discussed below.

BRIDGEPORT RENTAL AND OIL SERVICES

The 26 acre BROS site is a former oil processing and reclamation facility located in Bridgeport, New Jersey. The predominant feature on the site is an unlined 11.8-acre lagoon averaging 12 to 18 feet in depth with the greatest depth at 60 ft. A thick layer of heavy oils laced with construction debris, drums and other trash floats on the surface. There are also several large, partially submerged tank trucks in the lagoon. Some 80 storage tanks and vessels ranging in capacity from a few thousand gallons to greater than 300,000 gal are also present. The majority of the tanks are either empty or contain bottom sludges with only two of the larger tanks containing substantial quantities of liquids.

There is an eight to ten acre area of land adjacent to the lagoon with stressed vegetation. This damage occurred when the dike surrounding the lagoon was breached, spilling some of the lagoon's contents. There are visual seeps around the lagoon and into the adjoining freshwater ponds. Waterfowl are constant victims as they attempt to land on the lagoon surface.

The bottom of the lagoon is unlined; however, a thick layer of oily sludge on the bottom retards exfiltration. By June 1982, the level of the lagoon had risen to within 6 in. of the top of the dike. This situation required an immediate removal action. This action included mobilization of the USEPA's transportable activated carbon unit. This mobile treatment system was used to lower the lagoon level by approximately 2 ft, thus developing adequate freeboard. This action involved the removal, treatment and discharge of approximately 5,000,000 gal of treated water to Timber Creek.

Camp, Dresser and McKee, Inc. (CDM) initiated a Remedial Investigation[1] in the Fall of 1981 to determine the extent and severity of contamination at the site. Concurrent with the emergency action, the scope of this effort was redirected to determine the most cost-effective method to lower the lagoon level even further. Upon completion of this effort, the USEPA and the State of New Jersey entered into a Superfund State Contract on Oct. 29, 1982, to design and implement the initial remedial measures at the site. The objective of the initial remedial measure was to reduce the liquid level in the lagoon to ensure that overflow of the liquid over the dikes would be delayed for a substantial period of time while alternatives for the long term remedial action were being evaluated.

To determine the most cost-effective approach to the initial remedial measure, sampling was begun to characterize the contents of the lagoon. Samples of the lagoon oil and aqueous phase were taken at several locations and various depths and were analyzed at one of the USEPA contractor laboratories. Some limited data were available from the testing during the operation of the USEPA's mobile treatment system. These chemical data were used as a basis for designing initial treatability studies of the liquid wastes.

The general characteristics of the liquid wastes were: TOC, 180-220 mg/l; COD, 720 mg/l; five-day BOD, 90 mg/l; TSS, 690 mg/l; VSS, 300 mg/l; and oil and grease, 80 mg/l. In general, the waste is composed of approximately one-third volatile organics, one-third large molecular weight oily-type materials and the remaining one-third is generally uncharacterized and consists of a variety of organic compounds. The organic species found in significant quantities were benzene, trans - 1-2, dichloroethene, methy-
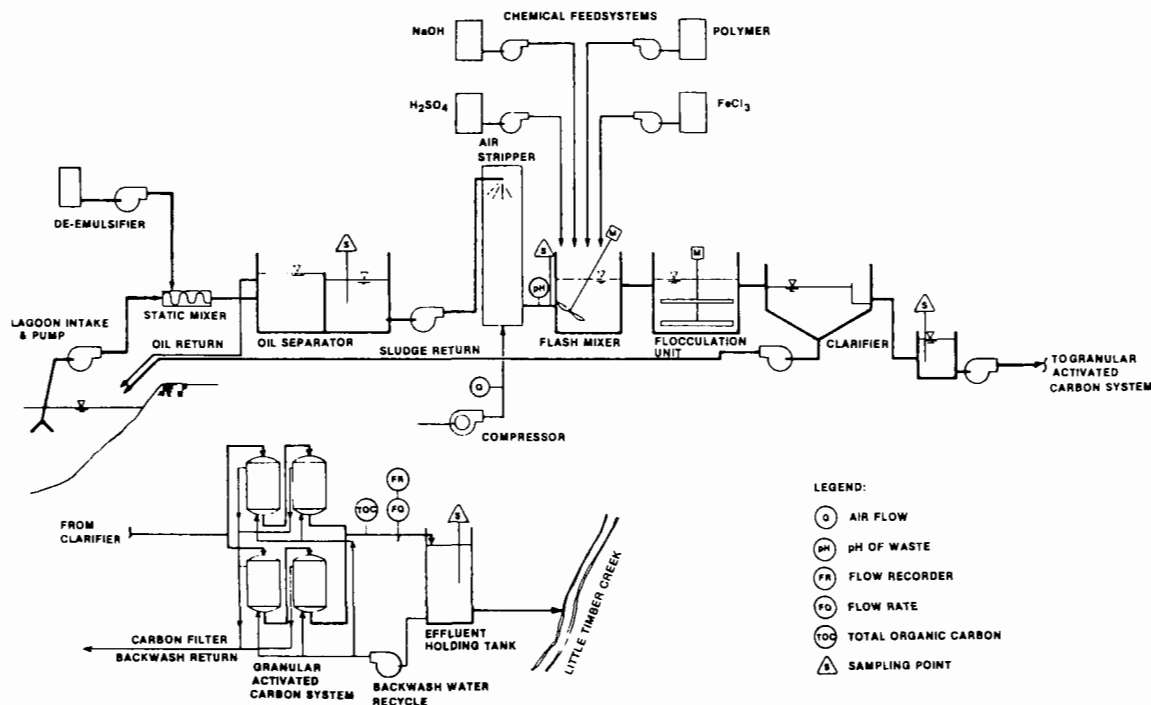
Figure 1
Treatment Process Schematic Bridgeport

lene chloride and toluene, all having concentrations around or above 1 mg/l. The inorganic substances of concern are lead and zinc, while most of the remaining metals have relatively low concentrations.

Oil Layer

The oily layer of the lagoon had a very high viscosity. The oily layer actually moves about the surface of the lagoon depending upon the wind direction. It contained levels of PCBs close to 450 mg/l. A wide variation of metal species were present in the oil with a significant difference in concentrations between the organic liquids and aqueous samples. Several metals concentrations were, however, found in the 1-10 mg/l range. A major element of any remedial actions taken at the site will involve dealing with the physical and chemical characteristics of the oily layer.

The level of the lagoon could have been lowered either by treating the underlying aqueous phase or by treating a combination of the oily surface layer and the aqueous phase. Although the oily surface layer represented a significant threat to the environment, it was determined that it could be more appropriately addressed during the long term remedial action rather than under the initial remedial measure because of difficulties of handling and disposal. Moreover, total removal of the oily layer would only reduce the level of the lagoon by 1 to 2 ft.

A work group consisting of personnel from the USEPA, CDM and the New Jersey Department of Environmental Protection was formed to make all decisions on the technical aspects of the project. The group decided that the initial remedial measure would be to treat the aqueous phase only. The work group also decided that the level of the lagoon should only be lowered to the level of the surrounding groundwater to maintain hydraulic equilibrium between liquid levels and lessen the possibility of breaching the bottom "seal," which was a result of the bottom sludges. This would require lowering the liquid level by approximately 12 ft, or treating approximately 35,000,000 gal of the aqueous phase of the lagoon.

The work groups established discharge limits for Total Organic Carbon (TOC) for the interim treatment system. TOC was used because of the multitude of organic compounds present at the site. Since most of these compounds were present at concentrations in

the 50-100 μg/l range, monitoring for TOC would markedly simplify the analytical process. The discharge limits agreed upon for TOC were 50 mg/l daily average over a 30-day period with a daily maximum of 100 mg/l.

The recommended wastewater treatment process was based upon the raw water quality data, effluent discharge limits and several bench scale and pilot tests. Final design criteria were established during the design project. A process diagram is provided in Figure 1 with the unit processes described in the next section.

Wastewater System Design

Oil Separation. The removal of oil at the beginning of the treatment process would protect subsequent processes from any heavy concentrations of emulsified, non-aqueous organics. The oil treatment process consists of addition of a demulsifier followed by a settling to allow the oil to float to the surface for collection and removal.

Air-Stripping. Air-Stripping was recommended for the removal of most of the volatile organics to reduce organic vapor levels near open process tanks and to maximize the life of the carbon adsorption units. Laboratory studies indicated that air-stripping would reduce the TOC by 50-80 mg/l. A countercurrent packed tower with an air-to-water flow ratio of 50:1 was recommended.

Flocculation/Sedimentation. Flocculation and sedimentation were recommended prior to carbon adsorption. The process involves coagulant addition and pH adjustment to remove suspended solids, oil and inorganic compounds. A flash mixer, flocculation basin and sedimentation basin are used. Suspended solids discharges for this unit process are 30 mg/l. Bench scale studies were performed to select the coagulants and dosages for proper operation.

Granular Activated Carbon (GAC). A GAC unit was recommended as the most effective method of removing the remaining organic compounds. The recommended process includes two dual-column adsorption modules operating in parallel. Each of the parallel systems consists of two carbon beds operated in series; each column has an empty bed contact time of 30 min. Information from the operation of the USEPA's mobile carbon treatment

Table 1
Concentration of Organic Contaminants Found in the
Groundwater at the Sylvester Site

POLLUTANT	HIGHEST CONC. FOUND IN GROUND WATER (PPB)
Vinyl Chloride	950
Benzene	3,400
Chloroform	31,000
1,1,2-Tricholoroethane	17
Ethylene Chloride	73,000
Tetrachloroethylene	570
Trichloroethylene	15,000
Xylenes	10,000
Methyl Isobutyl Ketone	21,000
Methyl Ethyl Ketone	80,000
Chlorobenzene	1,100
Methylene Chloride	122,500
Toluene	29,000
Ethyl Benzene	1,200
1,1-Dichloroethane	15
t-1,1-Dichloroethane	18,000
1,1,1-Trichloroethane	2,000
Methyl Methacrylate	3,500
Ethyl Chloride	320
Tetrahydrofuran	1,500,000
2-Butanol	3,560
Dimethyl Sulfide	3,500
Diethyl Ether	20,000
Methyl Acetate	2,400
Isopropyl Alchol	26,000
Acetone	310,000

system and bench scale studies was used as a basis for the selection of GAC.

Equalization Basin. A holding tank was recommended at the end of the treatment system to ensure the quality of the effluent before its discharge to Timber Creek. In the event that the quality of the effluent did not meet the discharge limits, the effluent would be returned to the lagoon.

Disposal of Process Sidestreams. It was recommended that the side streams be returned to the lagoon. These recycle streams include collected oil, backwash from the carbon units, sludge from the sedimentation basin and other miscellaneous streams such as personnel and equipment decontamination water. The spent carbon could either be regenerated or disposed off-site.

The design of the interim treatment was completed by CDM. The construction and operation is being accomplished by the U.S. Army Corps of Engineers. The treatment plant was fabricated and put into operation in December 1983; however, the system was shut down during the winter months. Operation of the treatment plant has resumed.

SYLVESTER HAZARDOUS WASTE SITE

The Sylvester site is a six-acre site in Nashua, New Hampshire, which was originally used as a sand borrow pit for a number of years. During the late 1960s, the operator of the pit began an unapproved and illegal waste disposal operation, apparently intending to fill the excavation. Household refuse, demolition materials, chemical sludges and hazardous liquid chemicals were all dumped at the site at various times. The household refuse and demolition materials were usually buried, while the sludges and hazardous liquids were either mixed with the trash or were allowed to percolate into the ground adjacent to the sand pit. Some hazardous liquids were also stored in drums which were either buried or left on-site. While it is impossible to estimate the total quantities of waste materials discarded at the site, the USEPA has documented that over 800,000 gal of hazardous waste were discarded there during a ten month period in 1979.

Groundwater Contamination

A contaminated groundwater plume is moving from the site toward Lyle Reed Brook. The uncontrolled plume had the potential of contaminating all private drinking water wells between the site and the Nashua River as well as becoming a major source of stress on the Nashua River. In addition, Lyle Reed Brook would not be able to support any aquatic life and would pose a direct threat to human health at the adjacent trailer park from volatilization of the organic pollutants in the brook.

The USEPA used CERCLA emergency funds to offset the threat by installing a groundwater interception and recirculation system at

Table 2
Suitability of Treatment Processes at the
Sylvester Site, New Hampshire

UNIT OPERATIONS	VOLATILE ORGANICS	NON-VOLATILE ORGANICS	INORGANICS
Air Stripping	Inadequate Removal	Not Suitable	Not Suitable
Stream Stripping	Effective Concentrated Technique	Not Suitable	Not Suitable
Carbon Adsorption	Inadequate Removal	Effective Removal Technique	Not Suitable
UV-Ozone	Not Suitable Due to High Concentration	Not Suitable Due to High Concentration	May oxidize and precipitate some metals
Biological	Effective Removal Technique	Effective Removal Technique	Not Suitable Metals Toxic
Wet Oxidation	Not Suitable Due to Low Concentration	Not Suitable Due to Low Concentration	Not Suitable
Reverse Osmosis	Inadequate Treatment	Not Applicable	Difficult Operation
pH Adjustment Precipitation	Not Applicable	Not Applicable	Effective Removal Technology
Electrodialysis	Not Applicable	Not Applicable	Inefficient Operation/ Inadequate Removal
Ion Exchange	Not Applicable	Not Applicable	Inappropriate Technology-Difficult Operation
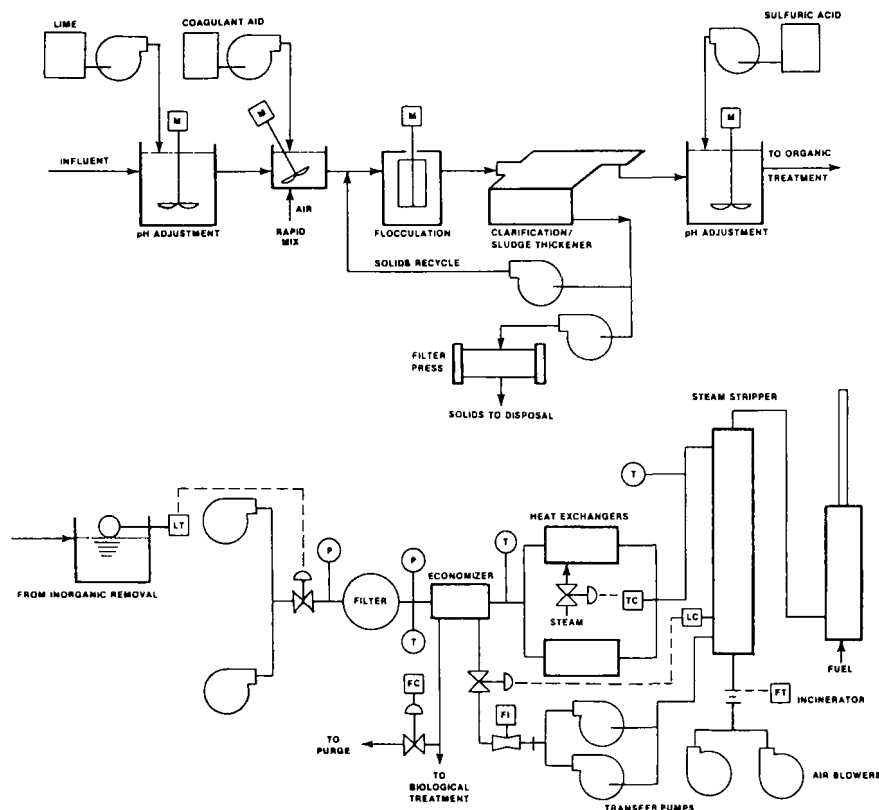
Figure 2
Process Schematic, Sylvester Site

the site in November, 1981. The purpose of the system was to retard further migration of the plume until a remedial action could be implemented. The system operated until October, 1982, when it was replaced by the first phase of remedial action.

The New Hampshire Water Supply and Pollution Control Commission has been directing efforts to contain and clean up the site using a two-phased approach for managing contamination. Their approach was developed as a result of the Remedial Investigation and the Feasibility Study[2] completed by Roy F. Weston, Inc. in January, 1982. The project design was reviewed, approved and funded by the USEPA in July, 1982, as the most cost-effective remedial alternative that adequately protected human health, welfare and the environment.

The first phase of the remedial action involved containment of the contaminated plume. This step required the installation of a bentonite slurry wall reaching depths of up to 90 ft in order to key it into bedrock. Then the entire 20-acre area was covered by an impermeable surface cap. The immediate purpose of the cap was to temporarily contain the contaminated groundwater while the groundwater treatment plant was designed and built. The second purpose of the installing the slurry wall and cap was to exclude clean water from entering the contaminated site once groundwater treatment was initiated. The implementation of this phase was completed in October, 1982.

The second phase of the remedial action was to design and build a groundwater treatment system capable of reducing the groundwater contamination to an acceptable level. The initial treatability work, completed as part of the feasibility study, was comprised of bench scale treatability studies using representative groundwater samples.

The Remedial Investigations showed that there were high concentrations of heavy metals as well as volatile and extractable organic concentrations in the groundwater under the site (Table 1). No one unit operation is capable of removing all of the contaminants. The treatability studies evaluated the potential of different unit operations to adequately remove particular groups of

contaminants. The development of an appropriate treatment train capable of effectively removing all contaminant groups is illustrated in Table 2.

The data clearly show that only two treatment trains will adequately treat the contaminated groundwater to the required levels. Both treatment trains required the initial removal of inorganic materials by chemical neutralization and precipitation methods. This requirement is the result of the high concentrations of iron and manganese (averaging 350 mg/l and 80 mg/l respectively) which precipitate out of solution in any process that introduces air in to the groundwater. The introduction of air into the groundwater results in the plugging or fouling of the organic treatment system.

The first suitable treatment train uses steam stripping to remove volatile organics while the second train uses biological methods. The feasibility study estimated the minimum treatment rate for both trains to be 35 gal/min, 24 hr/day continuous treatment, and the optimum treatment rate would be 100 gal/min. Upon the completion of a supplement to the feasibility study[3] in July 1982, the optimum treatment rate was later revised to 300 gal/min continuously. The supplement provided additional information about the costs associated with various groundwater treatment rates. This increase in the rate of treatment reduced the expected treatment time from 6.2 to 1.7 years. This period is based on the estimated effectiveness of a 90% reduction of all contaminants from two full flushes of the contained volume.

The operation of a pilot plant was necessary prior to the design of the full-scale plant because of the wide variations in the concentration of individual pollutants. The design for the pilot plant was completed in November 1982, the unit was built on the Sylvester site and experiments were begun in February, 1983. The plant, designed to remove inorganics and volatile organics from the groundwater that was pumped from three on-site wells, is shown in Figure 2.

The inorganic chemical treatment process is designed for the removal of iron and manganese. This process consists of chemical precipitation of heavy metals, pH adjustment of the wastewater

and sand filtration to remove the precipitated metals. In the pilot tests, iron removal was greater than 99% under all conditions, and manganese removal was greater than 99.8% at pH's of 10 and 11, with polymer doses between 0.5 and 1.0 mg/l.

The next process step is removal of the volatile organic compounds using a High Temperature Air Stripper (HTAS). The contaminated groundwater (with the metals removed) is preheated in two heat exchangers, one an economizer and the second a trim heat exchanger, before entering the column in which steam strips off the organics. Over the range of operating temperatures tested, all of the priority pollutants and more than 75% of the alcohols were removed from the wastewater.

In addition to the above pilot tests, bench and pilot scale treatability studies were conducted on distillation, incineration and biological treatment systems. The distillation studies were conducted by Artisan Industries, Inc. The purpose of their studies was to determine the feasibility of concentrating the organic contaminants present in the HTAs condensate to 50-60% organics while leaving the bottoms free of volatile organics. The data indicate that it is technically feasible to make a reasonable separation of the volatile organics from the HTAS condensate by standard distillation techniques. The limitations of this unit process are the need for a feed liquid containing only very small amounts of noncondensible gases (i.e., air) and the need for a vapor phase activated carbon solvent recovery system to remove the remaining solvent vapors from the condensers. These requirements increased the final cost of this process much above the incineration alternative.

The incineration studies were conducted by Trane Thermal, Inc. The purpose of these studies was to determine the optimum incineration design for the destruction of the aqueous waste and to determine the amount of fuel required per pound of waste. The aqueous wastes were generated in the pilot plant by passing the effluent air stream from the HTAS through a condenser. A destruction efficiency of tetrahydrofuran for all three test runs greater than 99.98% was attainable. The quantity of tetrahydrofuran collected was below detectable limits of 1.5 μg. The tests indicate that a residence time of 1.0 sec at 1500°F temperature will be sufficient for achieving a 99.99% destruction efficiency of tetrahydrofuran, the principal organic hazardous constituent.

Hydrocarbon emissions were also evaluated as a function of incineration temperature for optimum conditions. The studies indicated that the presence of aqueous waste did not increase the hydrocarbon emissions. Therefore, almost all the unburned hydrocarbons were the result of incomplete combustion of the fuel. Since the heating value of the aqueous waste was determined to be less than 0.5%, the amount of fuel required per pound of waste varied from 5114 BTU at 1450°F to 6910 BTU at 1600°F.

The biological treatment studies were conducted by Environmental Engineering Consultants, Inc. The purpose of these tests was to establish the treatment efficiency of activated sludge, aerated lagoon and rotating biological contactor systems on the HTAS effluent. All three systems operated at high levels of efficiency in removing the total phenols and the extractable organics of concern. The operational differences between the three systems were not significant enough to eliminate any system. Therefore the activated sludge system was chosen on the basis of the economic analysis.

A Supplemental Record of Decision on the groundwater treatment alternative selection was approved in September 1983. The construction contract was awarded in April 1984 and will be completed by the Fall of 1984.

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CLEANUP OF RADIUM PROCESSING RESIDUES IN A HIGHLY URBANIZED AREA

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INTRODUCTION

The isolation of the element radium by Pierre and Marie Curie in 1898 introduced the world to the "miracles" of radioactivity. Pitchblende, the mineral from which radium was originally refined, was known to exist in only a few locations and, consequently, the price of the material increased with the expanding use of radium for research and treatment of cancer.

Soon carnotite, another element with high radium content, was discovered in the Colorado Rockies. During the early 1900s, large amounts of carnotite ore were shipped to Europe to be refined. But by 1912, war in Europe threatened those refining operations and, faced with the possible shortage of refined radium, the United States Bureau of Mines entered into an agreement with American medical research institutions to form the National Radium Institute for the purpose of demonstrating the feasibility of radium refining and to produce enough radium for research and medical needs.

The National Radium Institute conducted pilot studies on radium refining near the outskirts of Denver, and by 1914 a full-scale production facility was completed and in operation. By 1918, over 7g of pure radium had been refined and the experiment was judged a success. The Institute was closed and the equipment sold. Attracted by the high prices offered for radium, many other refining operations began in the Denver area, utilizing the proven Bureau of Mines process as well as a variety of other processes.

The discovery of very rich near surface pitchblende deposits in South Africa proved fatal for the flourishing U.S. radium industry as prices plummeted and operations ceased or were converted to production of other materials by the mid-1920s.

As mining went through subsequent cycles of prosperity and depression, Denver grew to become the largest city in the Rocky Mountains, developing a diverse economic base including agriculture, petroleum and the largest concentration of federal employees outside of Washington, D.C. The population grew and the surrounding prairies first became suburbs and then part of the expanding metropolitan core. Defunct radium processing operations, once located in fringe or industrial areas, were engulfed by the expanding urban development. Since radium processing residues made excellent fill, they were incorporated into streets, railroad embankments and other properties.

In 1979, Hendricks of the USEPA discovered a reference to the National Radium Institute in a 1916 U.S. Bureau of Mines document. Subsequent investigation identified the property, and radiation surveys confirmed extensive low-level radioactive contamination of the property, including buildings and soils on the site.

Following notice of the potential for problems on other properties, the State of Colorado, the USEPA and the U.S. Department of Energy (DOE) began a series of studies to locate the contaminated areas and identify the associated hazards. In 1981, the Denver Radium Site, consisting of 31 identified properties, was placed on the Superfund National Priorities List. Remedial investigations were performed for most of the sites by the Colorado Department of Health in 1981 and 1982. In December 1983, CH2M HILL, the USEPA Zone II REM/FIT contractor, was directed to complete the remedial investigations and feasibility studies for the properties in accordance with the National Contingency Plan (NCP) requirements.

The NCP sets forth the procedures for evaluating and selecting remedial actions at uncontrolled hazardous waste sites. The NCP specifies the steps to be taken as preliminary assessment, site inspection, remedial investigation, feasibility studies and design which is followed by the remedial action.

The feasibility study develops and considers remedial actions. The NCP defines remedial actions as:
"Those actions consistent with permanent remedy taken instead of, or in addition to, removal action in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare of the environment." (40 CFR 300.68)

For the Denver Radium Site, the above paragraph is interpreted to mean actions which would reduce the exposure to ionizing radiation and/or radon gas from radium residues to prevent or minimize the associated danger to public health, welfare or the environment both at present and in the future.

DENVER RADIUM SITE

The properties under study range from public streets and an alley to parks, vacant lots, industrial and commercial properties and a private residence. The actual number of contaminated properties included in the Denver Radium Site has varied slightly with further studies and remedial actions. Of the 31 included on the original listing, three have been decontaminated by the owners and checked by the Colorado Department of Health. However, several additional properties contiguous to some of the original Denver Radium Site properties have been identified for further investigation as potentially contaminated properties because the designated properties they abut are contaminated up to, and possibly across, property lines.

These continuous locations and the remaining 28 properties of the original 31 were grouped, the groupings based on similar characteristics or contiguous locations. A brief description of the groupings and properties is presented below:

Group I: Four adjacent properties which occupy a full city block in an industrial district. The area is used for light industrial and commercial activities including a tombstone manufacturer, equipment manufacturer and miscellaneous warehouse and office space. The probable source of contamination for all the properties was a radium mill operated in the early 1920s in what had been a brewery. A maximum value of 452 pCi/g has been measured at this site.

Group II: Two nearly adjacent properties and surrounding areas in an industrial district. One operated as an analytical/research laboratory until recently; the other is a scrap metal recycling operation covering a full block and littered with massive piles of scrap metal. Previously, the latter property had been the location of a Radium Company of Colorado mill. The surrounding properties include commercial space, railroad tracks, a highway department equipment yard and offices. Maximum concentration of radium at this site was 931 pCi/g.

Group III: Two adjacent properties and surrounding areas in a mixed residential, commercial and light-industrial neighborhood. On the larger property, a mill and refining operation existed until it was totally destroyed by fire in the 1950s. The debris remaining after the fire was bulldozed into the building basement and the site leveled. The building across the street, reported to have been the mill office, is currently used by a commercial lighting manufacturer. Surrounding areas include railroad tracks, a packaging operation and commercial space. A value of 836 pCi/g was measured in soils in open areas, and 1956 pCi/g was measured in the crawl space of the building.

Group IV: One property in an industrialized area. This brick manufacturing plant occupies the site of the original National Radium Institute. Though most of the Institute's buildings were removed prior to the construction of the brick plant in the 1950s, a small office building and a laboratory building remain. Attached alpha of 632,000 dpm/100cm² was measured in the office building.

Group V: The railroad property contiguous to the Group IV property. The properties in Groups IV and V, though physically adjacent to one another, were separated for reasons of scheduling.

Group VI: Seven open land areas scattered throughout the Denver Area. Properties include a mined gravel pit used for a landfill, a city park, an alley, railroad tracks, a waterline right-of-way used as a parking lot, a vacant lot and the grounds of a chemical plant. The contaminated portion of each property is on open land, and no buildings or contiguous properties were identified as contaminated. A maximum value of 2775 pCi/g was measured on these properties.

Group VII: Eight street segments located in three clusters. The streets are located in urban areas near downtown Denver, passing through residential, and commercial areas and public parks including the Denver Botanical Gardens. Contamination is thought to be contained in a .13 cm asphalt layer in the roadways. Approximately 38 blocks of street have elevated radioactivity, with a maximum reading of 51 microR/hr.

Group VIII: A chemical plant and adjacent railroad properties. This plant has a current Radioactive Materials License from the State of Colorado and has been in continuous use since the early 1900s when radium was refined at the site. Maximum values of 0.145 WL and 2408 pCi/g were recorded in buildings and open areas, respectively.

Group IX: A pancake restaurant, surrounding parking lot and adjacent building. The site, which originally housed a radium laboratory, is on one of Denver's busiest streets and is surrounded by commercial property and residences.

Group X: A large manufacturing facility which had originally been a cotton mill, was converted to a radium mill and more recently has been a mining equipment manufacturing plant.

Group XI: Originally a private residence, now used as a real estate office. The owner of this property has done some cleanup of the building; however, the grounds of the property are also contam-

inated, and further remedial work may be required. A maximum value of 199 pCi/g was originally measured at this site.

REMEDIAL ALTERNATIVES AND ISSUES

The diversity of properties and degree of radioactive contamination has led to the consideration of a variety of alternative remedial actions. These actions, summarized in Table 1, raise a variety of issues which complicate the evaluation and comparison of alternatives. Some of these issues are briefly discussed in the following paragraphs.

Table 1
Denver Radium Sites Possible Remedial Actions

The actions listed below represent alternatives for cleanup of the Denver Radium Sites that could be considered in the preliminary screening step of the Feasibility Study.

Contamination Removal Options
*Material excavation and removal
*Structure demolition and removal
*Physical cleaning of surfaces (decontamination)
Disposal Options (required for removal options)
*On-site (temporary or long-term)
*Off-site (federal or commercial disposal sites)
*Reprocessing to extract uranium and radium
Radiation Shielding (including radon control)
*Lead shielding
*Concrete mixtures
*Asphalt
*Soil
Other Actions
*Area exclusion (fencing, condemnation, and use restrictions)
*Dilution (with clean soil)
*Ventilation of enclosed areas (for radon control)
*Sealants (for radon exclusion from enclosed areas)
*No action
Combinations of the Above Actions
*(Such as shielding and ventilation in basements, with physical cleaning of floors and walls)

Cleanup Standards

Since the radiation exposure from radium processing wastes has potential health effects similar to the potential effects of exposure to uranium mill tailings and the causal mechanisms are the same, the USEPA has chosen to apply the inactive uranium mill tailings cleanup standards (40 CFR Part 192) to the radium processing wastes present at the Denver Radium Site. These regulations clearly emphasize remedial actions which remove the source of contamination from the public; however, the NCP criteria require careful consideration of all alternatives.

The standards in 40 CFR Part 192 provide direction for cleanup of both structures and open land areas as follows:
*For contaminated buildings, reduce the radon decay product concentration to less than 0.02 Working Level and reduce the gamma radiation to less than 20 microR/hr above background
*For contaminated open areas, reduce the surface radium content to less than 5 pCi/g above background averaged over the top 15 cm of soil or to less than 15 pCi/g above background averaged over any 15 cm of soil below the top 15 cm.

In addition, the feasibility studies will address compliance with the State of Colorado Standard for maximum alpha activity from nonuranium radioactive material. The Colorado standard is 300 dpm/100 cm² attached alpha and 20 dpm/100 cm² removeable alpha.

Defining Action Levels

Applying the above standards to a given site presents several difficulties, including the selection of measurement techniques and the

determination of background levels. Devices commonly used for field radioactivity measurements are often calibrated in units of counts per minute or microR/hr. Conversion between these units or to radium concentrations in soils is difficult. Thus, depending on the field instrument used, the instrument readings may not be suitable for comparison to the standards. Field measurement techniques for determining the radium concentrations in soil are very cumbersome, and laboratory techniques usually require weeks. Thus, during the excavation process, it is difficult to determine whether all the contaminated material has been removed.

Variability in background measurements can also complicate data evaluation. Natural background is affected by elevation and the presence of naturally radioactive materials. Background in Denver is approximately 50% higher than at sea level due to higher levels of cosmic radiation at its 5000 ft elevation. Natural background levels can be further elevated due to the naturally higher uranium content of some local rock.

At certain sites, background is more difficult to evaluate. A brick manufacturing site is totally covered with raw clay, much of which has a small, but measurable naturally elevated level of radioactivity. A second site which manufactures tombstones is covered with 15 years' accumulation of granite chips, which also has an elevated natural radioactivity. At this site, background readings could also be influenced by a commercial sandblasting abrasive which was found to contain significant radiactivity.

Radon gas levels can also vary due to factors that are not associated with radioactive wastes. Buildings constructed of naturally radioactive substances (granite, brick) or with effective weathersealing may have elevated radon levels totally separate from any contamination-related radioactive materials.

Nonradioactive Contamination

As illustrated above, the Denver Radium Site properties represent a cross-section of urban commercial and industrial uses. Although the initial focus of the investigation primarily involved the problem of radioactive contamination, information about the past uses of some of the properties indicated that the response planning for some of the sites should not be limited to the hazards of radium processing wastes alone. Some of the sites had been the location of chemical processing or manufacturing operations for nearly a century, while others had known or suspected past uses such as landfill or dump sites, oil recycling plants or wood preserving operations. Therefore, for health and safety reasons and disposal site selection and design purposes, investigations of nonradioactive hazardous materials were added to the scope of the study.

The nonradiological hazardous materials potential of each of the properties was evaluated by conducting preliminary assessments and, as warranted, site inspections. Although not all of the preliminary assessments and site inspections have been completed, the investigations to date have revealed significant nonradioactive waste contamination, including locally high (up to 30 ppm) concentrations of carcinogenic and suspected carcinogenic organic compounds. The discovery of these organics triggered additional site evaluation to determine the extent of contamination and address these substances along with the radium wastes in the health and safety plan for site cleanup and in the selection and design of an off-site disposal facility.

Disposal Site Requirements

CERCLA required that the State assure the USEPA that a disposal site is available. For the waste from the Denver Radium Site, finding a suitable disposal site has proven to be a difficult task. Few hazardous waste sites will accept radioactive wastes and haul distances and the cost of using the commercial disposal facility at Hanford, Washington is prohibitive.

The similarity between the Denver Radium Site radioactive wastes and uranium mill tailings had led to consideration of co-disposal with uranium mill wastes at one or more locations in Colorado. Colorado has nine inactive uranium mill sites under study that are included in the DOE Uranium Mill Tailing Remedial Ac-

tion Program (UMTRAP). However, differences in the timing of the UMTRAP cleanup work and concerns about mixed (nonradioactive) wastes may complicate the use of an UMTRAP site. Therefore, additional studies are being performed to consider suitable alternative disposal sites.

Liability for Cleanup

The assignments of liability and enforcement are important aspects of all Superfund actions. It is important to investigate the existence of potentially responsible parties that are financially viable and, hence, could be compelled to cleanup a site or reimburse the Superfund for the costs of cleanup. Several aspects of this site involve complex and difficult responsible party issues. The first, most obvious challenge is tracing a chain of liability that extends almost three quarters of a century into the past. Business and government record-keeping was not as complete in the past as it is today. In addition, many of the records that did exist have been lost or destroyed. In addition, any pursuit of responsible parties must also address the difficult question of assessing liability against a party for activities that took place at a time when there was very little, if any, appreciation for the health hazards associated with exposure to radioactive materials.

Investigations of liability for the release must also address the responsibilities of various government entities. Since the U.S. Bureau of Mines was instrumental in the creation of the National Radium Institute, there is a possibility that the U.S. Government could have some responsibility for the release of radium processing wastes. In addition to the Bureau of Mines involvement, there have been some allegations that one of the Denver Radium Site properties was the location of a thorium processing operation from the Manhattan Project, the United States' World War II atomic weapons program. Thus, because of possible Government involvement, factual evidence related to the liabilities of the Federal Government is also being collected.

Some evidence also points toward a liability of the City and County of Denver for certain portions of the Denver Radium Site releases. The consequence of such a liability is that CERCLA requires a state cost share of a higher percentage of cleanup costs for publicly owned sites rather than the 10% required for other sites. The most obvious area of potential liability is in the contaminated streets and alleys. Since they have been the property and responsibility of the City and County of Denver since the days of the National Radium Institute, local government or its contractors could be held liable for any cleanup costs associated with the streets and alleys. Local government could also face certain liabilities due to the spread of radium contaminated soils to otherwise uncontaminated fill areas owned by private parties.

Interim Measures

Given the lead time required to complete remedial investigations, determine the cost-effective remedy for each situation, arrange for off-site disposal and prepare for the cleanup, the USEPA has initiated studies under its Superfund Immediate Removal authority to determine whether prompt actions are needed to protect people from exposure at any of the Denver Radium Site properties. This process began during the summer of 1984 when a Technical Assistance Team contractor investigated indoor radon and airborne alpha particle levels in occupied structures to determine whether temporary remedies, such as alpha particle fixation, installation of air cleaning devices or additional ventilation should be considered while arrangements are being made for a permanent remedy at the site.

This study may result in recommendations to use Immediate Removal funds to take steps toward reducing exposure l.evels in any of the buildings affected by Denver Radium Site contaminants. Since wintertime is typically the season of greatest concern due to building weatherproofing and lack of circulation of outside air, the time schedule for any Immediate Removal action will emphasize remedies that can be implemented in time to do the most good.

CONCLUSIONS

The Denver Radium Site, with its numerous and diverse contaminated properties, presents interesting challenges to the planners of remedial actions. The radioactive wastes are difficult to quantify due to the complexity of field investigation techniques and the degree to which the wastes have been disturbed by normal urban activities during the decades the wastes were forgotten or ignored. In addition to the radioactive wastes, the remedial planning for the Denver Radium Site must address the problems posed by nonradioactive hazardous materials present in the contaminated soils. Some of the properties involved have a history of as much as 100 years of mixed industrial uses.

The presence of such nonradioactive hazards may have a significant bearing on the health and safety procedures used during site cleanup and the selection and design of disposal sites. The diversity of properties involved and the uniqueness of each property's history also present great challenges in the investigation of potentially responsible parties. Finally, because of the long lead time required to address all of the issues in a study of this nature, prompt actions should be considered in order to reduce the exposure of occupants of contaminated properties.

GLOSSARY

alpha particle—A decay product made up to two protons and two neutrons.

beta particle—A decay product consisting of a high-velocity electron, usually negative in charge.

dpm—Nuclear disintegrations per minute.

gamma ray—A decay product consisting of a photon, a quantum of electromagnetic energy having a characteristic wave length and frequency.

pCi/g—Picocuries of radium per gram of soil; a picocurie is a fractional portion of a curie, a unit of radioactivity equal to 3×10^{10} disintegrations per second.

mR/hr—One millionth of one roentgen per hour; a roentgen is the unit of radiation exposure in air due to X- or gamma rays.

working level—A measure of exposure to short-lived radon decay products in air; the working level equals 1.3×10^5 MeV of potential alpha energy from any combination of radon daughters per liter of air.

SUPERFUND PLANNING PROCESS FOR THE OMC HAZARDOUS WASTE SITE, WAUKEGAN, ILLINOIS

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INTRODUCTION

The purpose of the authors in writing this paper was to describe the feasibility study and planning process that was conducted by the USEPA to evaluate cleanup alternatives for the polychlorinated biphenyl contamination in Waukegan Harbor. The Feasibility Study was prepared by CH2M HILL under a national contract to assist the agency on site cleanup projects.

SITE DESCRIPTION

The OMC site is located on the western shore of Lake Michigan in Waukegan, Illinois. It is about 37 miles north of Chicago and about 10 miles south of the Wisconsin border (Fig. 1).

For the purposes of the feasibility study, the site was divided into four subareas:
- Slip No. 3
- Upper Harbor
- North Ditch area
- Parking Lot

High levels of PCBs in soil and harbor sediments in the vicinity of the OMC plant were discovered in 1976. The movement of PCBs through groundwater and surface water has contributed to Waukegan Harbor and Lake Michigan contamination; they have entered the aquatic food chain, accumulating in game and commercial fish.

The extent of cleanup is based on computer models of transport mechanisms in the area and the application of the regulations in the NCP.

The contamination of the sediments in Slip No. 3 ranges from 500 to 10,000 ppm PCB. Concentrations in excess of 10,000 ppm PCB occur in one localized area near the former industrial outfall. Approximately 305,200 lb of PCBs are in 10,900 yd³ of sediment in Slip No. 3. Because slip No. 3 contains very high concentrations of PCBs in a relatively small area, the engineering approach taken to reduce or eliminate the spread of PCBs is to reduce the contact of sediment and water and to reduce the concentration gradient that forces PCBs downward into the sediment.

The North Ditch drainage consists of areas of high PCB concentrations that are exposed to flowing surface water. The flowing waters, especially during storms, can wash the PCBs into Lake Michigan. Two subareas of the drainage also contain PCBs in high concentrations. This extreme concentration gradient forces PCBs to move downward into deeper sediments and the groundwater.

The engineering approach to reduce or eliminate the release of PCBs would be to eliminate their exposure to the flowing surface water and to reduce the concentration gradient in the areas of highest contamination.

The Parking Lot area contains contamination of soils that ranges from 50 to over 5,000 ppm PCBs. Approximately 277,700 lb of PCBs are contained in 105,800 yd³ of soil.

The Parking Lot contains lower concentrations of PCBs distributed in a very large volume of soil and over a large area. In the Parking Lot area, the pathway for the release of PCBs is through groundwater movement toward the lake.

The engineering approach to reduce or eliminate PCB spread from the Parking Lot would be to isolate the groundwater from contacting the contaminated material.
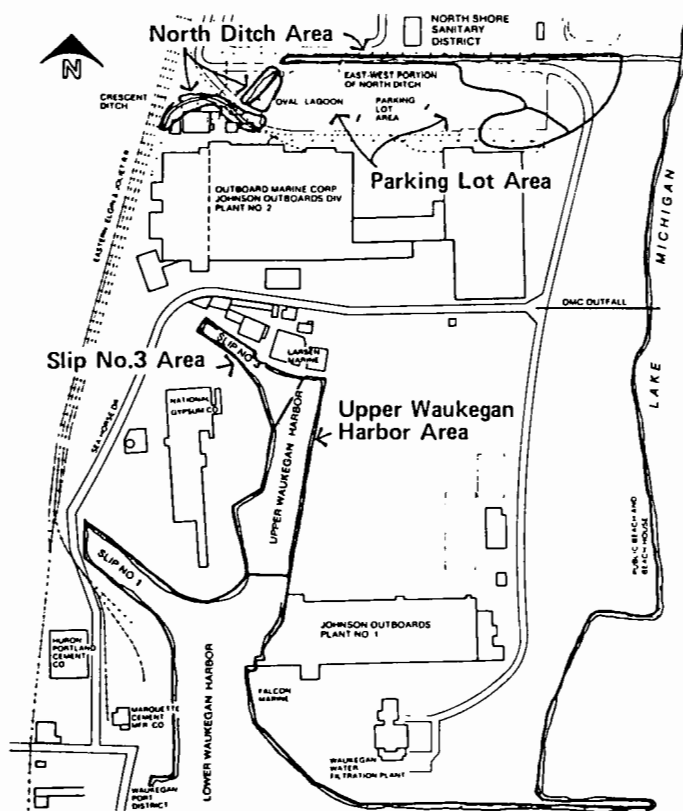
Figure 1
Site Map

o In-Place Destruction
o In-Place Fixation
o In-Place Separation and Removal
o Dredging
o Excavation
o Sediment Dispersal Control
o Surface and Ground Water Control
o Bypass
o Dewatering
o Fixation
o Water Treatment
o Onsite Storage/Disposal
o Offsite Storage/Disposal
o Transportation

Figure 2
Processes Evaluated in Feasibility Study

The Upper Harbor contamination of sediments with PCBs ranges from 50 to 500 ppm. Approximately 5,000 lb of PCBs are distributed in 35,700 yd³ of sediment.

The Upper Harbor contains lower concentrations of PCBs distributed in a very large volume of sediment and over a much greater surface area. This increased surface area provides a significant pathway whereby PCBs can contact the water and move out into Lake Michigan or enter the food chain.

The engineering approach to reduce or eliminate the spread of PCBs from the Upper Harbor is to reduce the surface area by which PCBs contact the water. The large volume, low concentrations and large surface area are considered.

The North Ditch area contamination of soils ranges from 50 to 10,000 ppm PCBs. Concentrations exceeding 10,000 ppm occur in one localized area. Approximately 495,500 lb of PCBs are in 70,800 yd³ of soil in the North Ditch area.

EVALUATION PROCESS

The purpose of the feasibility study was to review possible ways of treating the problem, to screen alternative actions and to present recommended alternatives for public review and comment. Over 70 possible processes were initially evaluated to determine their potential for contributing to PCB removal. These included various combinations of the technologies shown in Figure 2.

The processes retained from the preliminary screening were assembled into various combinations resulting in 21 cleanup alternatives for further study. How various processes were combined into one cleanup alternative for the North Ditch area is shown in Figure 3.

Finally, 12 alternatives and two subalternatives were selected for a more detailed examination. All of these alternatives were evaluated on the basis of the overall project objectives including:
•Effectiveness in cleaning up the site
•Technological feasibility
•Environmental soundness
•Protection of public health and welfare
•Cost-effectiveness

SUMMARY OF FINAL ALTERNATIVES

In Slip No. 3, the reviewed alternatives included excavating deep sediment, followed by dewatering in lagoons or barges, solidification of the sediment and transport off-site for disposal. These alternatives range from $7.6 million to $10.7 million.

In the Upper Harbor, similar alternatives were reviewed. Because of the greatly increased volume of sediment, costs ranged from $13.6 million to $24.8 million.

Alternatives were also developed to address the Upper Harbor and Slip No. 3 together. These alternatives included a combination of off-site removal and on-site containment. The costs ranged from $6.1 million to $9.3 million. Removal and off-site disposal of the most highly contaminated material from Slip No. 3 was considered as a subalternative, increasing the costs to $12.4 million.

Alternatives addressing the North Ditch and Parking Lot area included combinations of excavation, off-site disposal, on-site containment, capping and construction of a storm bypass sewer. These alternatives ranged from $740,000 for hot spot removal in the North Ditch area alone to $62 million for the North Ditch and Parking Lot areas together.

The combination of alternatives that was initially suggested to the public for implementation is shown in Figure 4. Under this recommendation, "hot spot" removal was advocated for Slip No. 3 and the North Ditch area. Dredging was advised for the Upper Harbor with dredge material being permanently placed in Slip No. 3. This process would have resulted in part of Slip No. 3 being permanently filled in. A storm sewer bypass was recommended for the North Ditch, and in-place containment was recommended for the Parking Lot area.

COMMUNITY RELATIONS PROGRAM

The USEPA conducted an extensive community relations program, allowing the public an opportunity to comment on the proposed plan. Following the first public comment period, and in conjunction with some additional information, the USEPA enlarged the recommended scope for harbor dredging, suggesting permanent encapsulation in Slip No. 3. The larger dredging project necessitated a larger containment cell. This option was again presented to the public for review. The Agency recieved significant
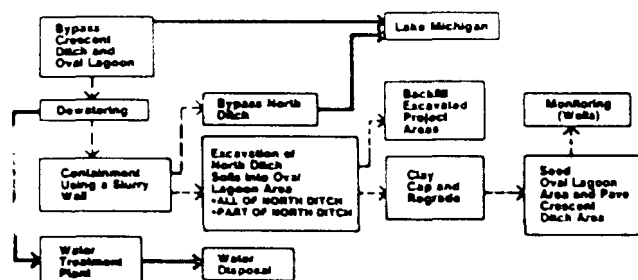
Figure 3
North Ditch Area
Alternative No. 4

Cleanup Action	Estimated Cost
SLIP NO. 3 AND UPPER HARBOR Remove Hot Spots and Dispose Offsite	$3,150,000
SLIP NO. 3 AND UPPER HARBOR Dredge, Dewater, and Dispose In Slip No. 3	6,100,000
NORTH DITCH AREA Remove Hot Spots and Dispose Offsite	740,000
NORTH DITCH AREA Contain and Cap	4,210,000
PARKING LOT Contain and Cap	3,210,000
TOTAL ESTIMATED COST FOR THE FIVE CLEANUP ACTIONS	$17,410,000

Figure 4
Estimated Costs
Alternative Selected for Implementation

objection to this larger containment cell during the comment period. The USEPA then tried to maintain the enlarged scope of the project requested during the first comment period, but reduce impacts on the harbor, which was the thrust of the comments during the second comment period, while simultaneously maintaining the cost-effectiveness of the project. This effort required preparation of an addendum to the feasibility project.

Also, during the decisionmaking process, the USEPA evaluated the "fund balancing" criteria of the NCP. Under these criteria, the USEPA can recommend a less costly alternative that provides similar protection if funds spent at one site would preclude response actions at other equally significant areas.

Therefore, on this project, the USEPA identified a cost-effective alternative and decided to implement a fund-balanced approach.

PLAN SELECTED FOR IMPLEMENTATION

First, in Slip No. 3, 5,700 yd³ of the most highly contaminated sediment from the localized "hot spot" will be dredged for off-site disposal. The estimated cost will be $3,150,000.

Next, the remainder of Slip No. 3 and the upper harbor will be dredged. All sediment exceeding 50 ppm PCB will be dredged and removed. A dewatering lagoon will be built on the OMC property adjacent to the harbor. The sediment will be dewatered in the lagoon and transported to the Parking Lot area for codisposal. This will cost an estimated $10 million.

In the North Ditch, hot spot removal and off-site disposal are recommended for implementation, with 5,500 yd³ of the most highly contaminated material to be excavated and hauled off-site for disposal in a chemical waste disposal site. It is estimated that this portion of the work will cost $740,000.

Next, slurry walls will be constructed to create an on-site containment cell in the vicinity of the hot spot removal. Contaminated sediment will be excavated for sewer construct. This sediment will be placed in the containment cell and will be capped in place. Then, a storm bypass sewer will be installed in the North Ditch. This construction will cost an estimated $4,210,000.

Lastly, the contaminated soil currently in the Parking Lot, the sediment from the harbor and the contaminated lagoon material will be disposed of together in the Parking Lot. Slurry walls and a clay cap will be used to contain the contaminated material. The estimated cost for this portion of the project will be $3,200,000.

The total estimated project costs will be $21,300,000.

Combined, these projects will remove more than 92% of the PCBs from Slip No. 3 and the Upper Harbor. They will also remove 57% of the PCBs in the North Ditch and Parking Lot area for off-site disposal. More than 98% of all the PCBs on-site will be effectively isolated from contact with the environment.

SITE CONDITIONS AND CORRECTIVE ACTION AT THE NORTH HOLLYWOOD DUMP

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INTRODUCTION

The North Hollywood Dump is located on the alluvial plain and in abandoned channels of the Wolf River in Memphis, Tennessee (Fig. 1). An uncontrolled dumping operation existed in the early years (mid-1930s onward), but aerial photographs of the site in the 1950s and 1960s show controlled access and a managed dumping operation. Now closed, the dump occupies over 70 acres, and the

Figure 1
Site Location of the North Hollywood Dump in North-Central Memphis, Tennessee. North Hollywood Street was Built Through the Dump in the Early 1960s

thickness of the refuse is estimated to be 20 to 25 ft. Most of the dump is covered with grasses, brush and trees. Approximately 5% of the dump area is not vegetated due to the presence of demolition debris, tar and other materials that will not support vegetation.

The USEPA conducted studies at the North Hollywood Dump and in the vicinity in 1979 and 1980. On the basis of their findings, a voluntary Technical Action Group (TAG) composed of the City of Memphis, Velsicol Chemical Corporation, Memphis/Shelby County Health Department and the State of Tennessee joined with the USEPA in 1980 to address problems at the site.

Short-term assessment of the dump was addressed first. A detailed site survey on a grid basis was undertaken, and a work plan for securing surface contaminants was developed.[1] In February, 1981, 89 drums of contaminated surface soils from the eastern portion of the dump were shipped to an approved landfill for disposal. The reseeding of newly-covered portions of the dump was completed in March, 1981.

The long-term objectives of the TAG Environmental Assessment and Action Plan for the North Hollywood Dump were established in March, 1981. The objectives are direct and concise, yet comprehensive. The goals were to:
- Determine the nature and scope of environmental problems existing on the dump and adjacent areas
- Determine the relationship of the dump to these problems
- Develop alternatives to remediate identified problems attributable to the dump

To accomplish the objectives, the investigative phase of the TAG program was divided into six major Task Elements:
- Existing Data Compilation and Interpretation
- Surface and Subsurface Hydrology
- Subsurface Water Quality
- Environmental Monitoring
- Report Preparation
- Program Management

TAG participants were involved in data collection and program management. The E.C. Jordan Co. was subcontracted by the USEPA's contractor, NUS Corporation, to undertake the fifth task report preparation.[2, 3] The company was hired to interpret site data and identify and evaluate corrective action alternatives.

PHYSICAL SETTING

The dump is bordered on the north by the westward-flowing Wolf River, on the east and west by surface water ponds and on the south by a residential area. The subsurface geology in the vicinity
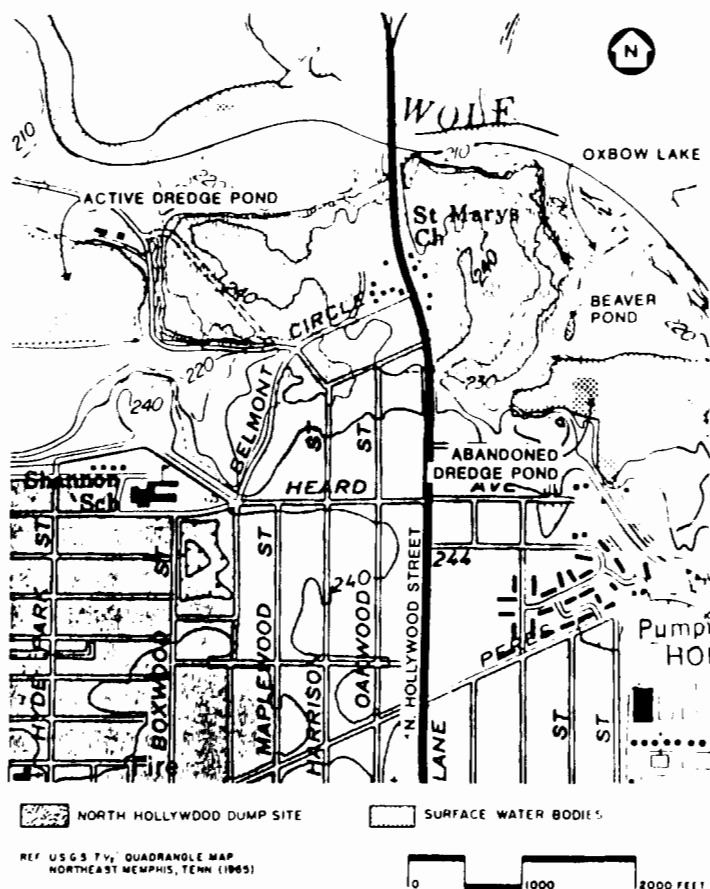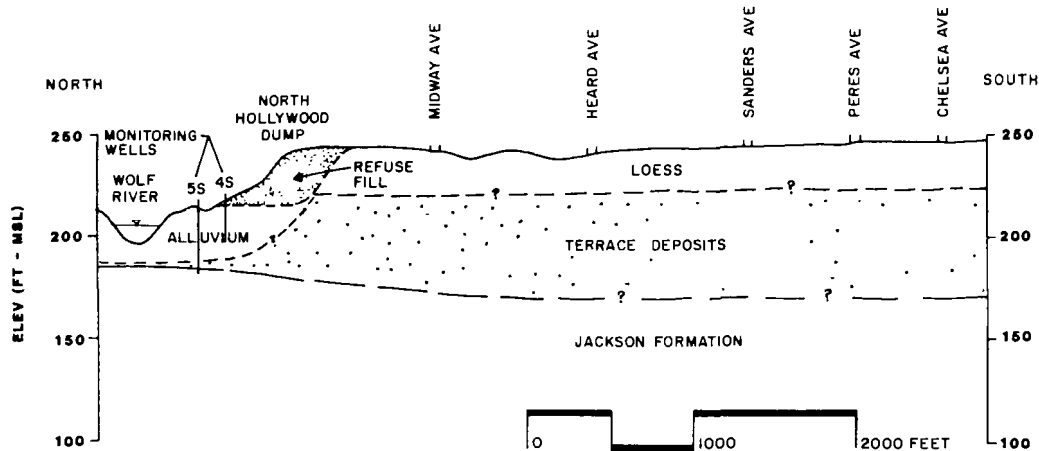
Figure 2
North-South Cross Section Through the North Hollywood Dump and Vicinity

of the dump, from youngest strata to oldest, consists of the following (Fig. 2):

- **Alluvium**—surficial sand and gravel deposits
- **Loess**—windblown silt deposits which are present over most of the Memphis area
- **Terrace deposits**—sand and gravel deposited by ancestrial streams and rivers
- **Jackson Formation**—200 ft thick deposit of marine clay
- **Memphis Sand**—700 ft thick sandy formation which serves as the principal aquifer for the city of Memphis.

— 210 — EQUIPOTENTIAL LINE

——▶ GROUNDWATER FLOW LINE

✤ MONITORING WELL LOCATIONS

GROUNDWATER LEVEL MEASUREMENTS
MADE ON JUNE 17, 1983

Figure 3
Horizontal Groundwater Flow Net of the Shallow Groundwater Regime in Alluvium and Terrace Deposits

The principal surface water bodies in the vicinity of the dump are the Wolf River; an abandoned dredge pond (40 acres), beaver pond (0.4 acres) and oxbow lake (2 acres) on the east; and an active dredge pond (32 acres) on the west. Surface water courses emanating from the dump flow to these adjacent water bodies.

At least two groundwater regimes exist beneath the North Hollywood Dump: (1) a shallow aquifer in alluvium and terrace deposits (Fig. 3), and (2) a deep aquifer in the Memphis Sand. Groundwater in the shallow aquifer flows to the north beneath the dump and discharges to the Wolf River and adjacent water bodies. The deep aquifer is isolated from the shallow aquifer by the thick clay deposits of the Jackson Formation. Therefore, any contaminated groundwater in the shallow regime which might emanate from the dump does not migrate to the deep aquifer in the Memphis Sand.

The TAG have used monitoring studies to compile chemical data related to the North Hollywood Dump. Low to moderate levels of chlorinated cyclodienes have been detected in some surface soil, surface water, sediment, groundwater and fish samples.

ENVIRONMENTAL PROBLEMS

The quantification and interrelationships of several factors were considered when determining the nature and scope of environmental problems existing at the dump and in adjacent areas. These factors included: (1) chemical transport modes, routes and rates (Fig. 4); (2) absolute concentrations and concentration gradients of chemicals in the environment; (3) anticipated duration of exposure; (4) potential receptors; and (5) health and environmental quality risks. On the basis of the assessment of these five factors, the following environmental problems were ientified:

- **On-Site Soils**—residual surficial contamination may pose a risk to public health and environmental quality; additionally, contaminants will be a future threat to adjacent surface water bodies via surface runoff.
- **Surface Water Bodies**—the presence of chlorinated cyclodienes in adjacent surface water ponds (maximum measured concentration of 0.001 mg/l, in associated bottom sediments (maximum concentration of 200 mg/l) and in whole fish (maximum concentration of 28 ppm) constitutes a potential health risk.
- **Shallow Groundwater**—the contaminants present within the dump could result in increased contaminant transport to adjacent surface water bodies via shallow groundwater flow and discharge.

REMEDIAL RESPONSE OBJECTIVES

The identification and evaluation of corrective action alternatives for existing or potential environmental problems at the North Hollywood Dump requires the establishment of appropriate remedial response objectives and cleanup goals. Chlorinated cyclodienes
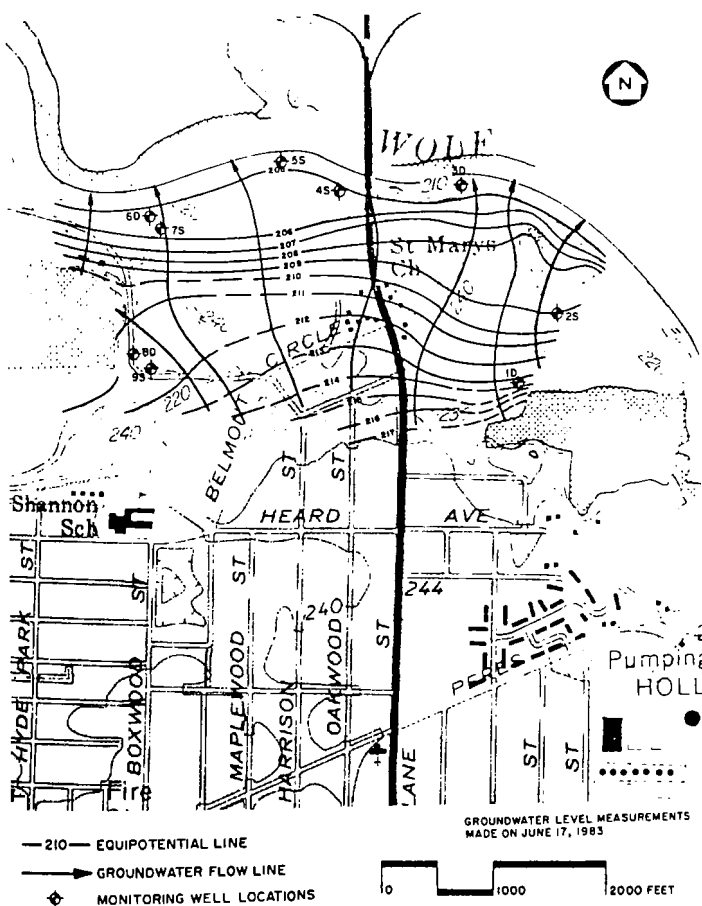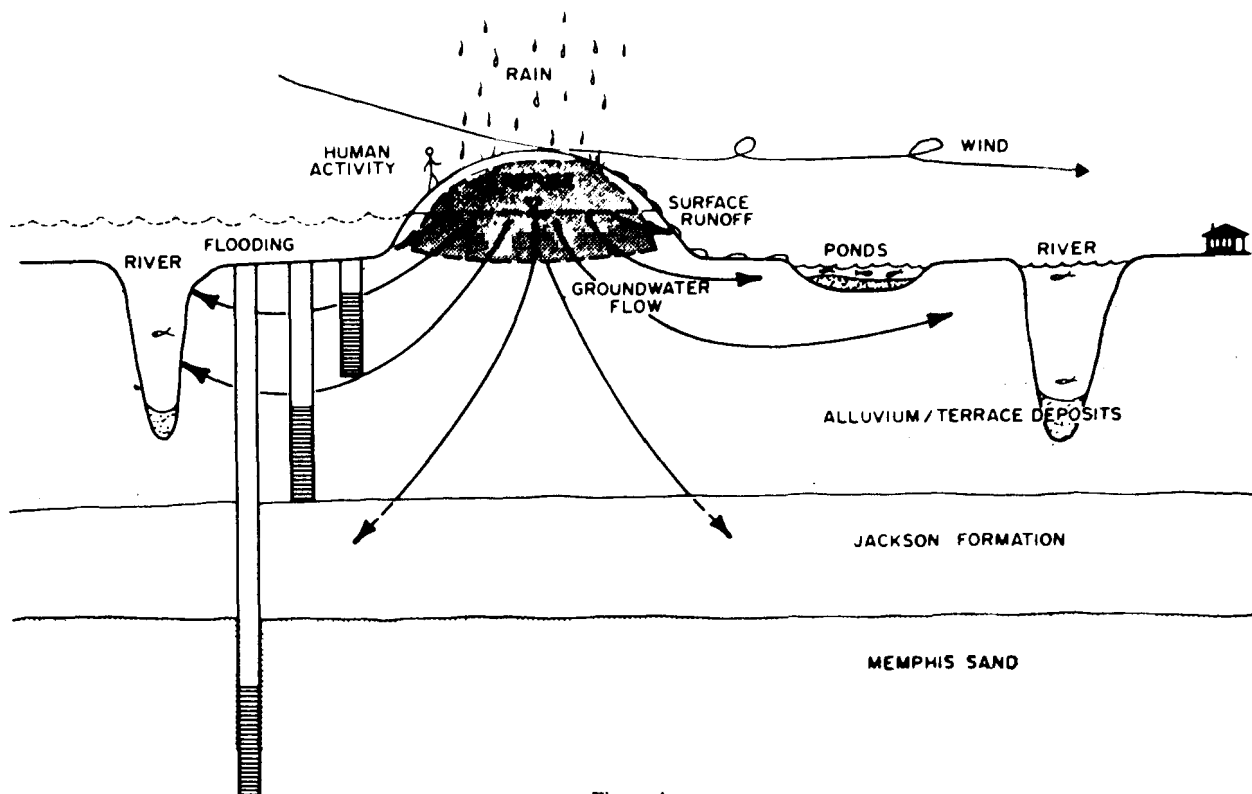
Figure 4

Conceptual Pathways for Contaminant Migration at the North Hollywood Dump. Environmental Problems Have Been Found to be Associated with Surficial Soils on the Dump Itself and Surface Water, Bottom Sediment and Fish in Adjacent Ponds. Shallow Groundwater Emanating from the Site is a Potential Environmental Problem.

are the key chemicals of concern since this class of organic compounds includes many pesticides and related compounds, generally exhibits a low solubility in water, has a high affinity for soil, has a low volatility and undergoes natural degradation.

Metals have been detected in the soils, sediments and waters at the site. However, their concentrations and environmental impact are considered less significant than those of the chlorinated cyclodienes. Moreover, remedial actions that mitigate the environmental effects of the chlorinated cyclodienes can also be expected to mitigate effects of inorganic substances.

ON-SITE SOILS

Very few specific, quantitative health criteria exist for the assessment of potential exposure routes via contact and/or ingestion of contaminated surface soil. Several independent criteria in the form of guidelines, experimental data and background studies relating to health risk via soil contact include: (1) Work Health Organization Guidelines for limits of pesticide ingestion based on body weight,[4] (2) lethal dosage (LD) experiments on animals[5] and (3) background levels of pesticides and related compounds in the environment.[5, 6]

Concentrations of total chlorinated cyclodienes in the soil range from less than 1 ppm to as high as 100 ppm. The lower value is close to background levels measured in several U.S. cities,[5, 6] while the higher value (100 ppm) is an order of magnitude higher than the highest background levels in U.S. cities.[5, 6] Jordan considered it appropriate to identify a narrow range of total concentration values as a response objective (10 ppm to 100 ppm) rather than a specific value within the range. A specific response objective within the range of values would be established on the basis of anticipated future land use options represented as "no use," "limited use" and "unrestricted use". A system response curve for surface soil under a "no action" scenario is shown in Figure 5.
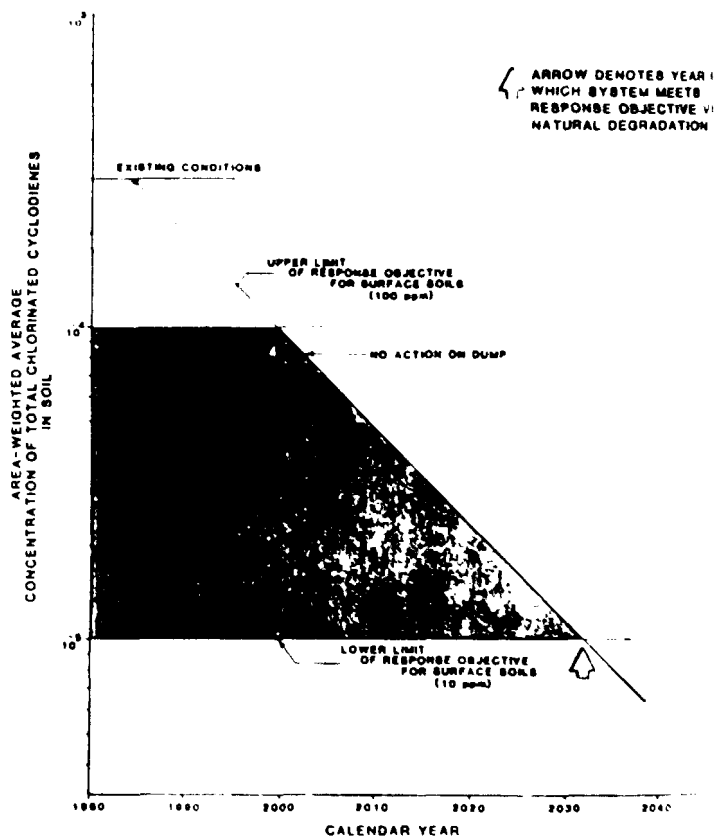
Figure 5

The System Response Curve for the North Hollywood Dump Surficial Soil Indicates the Length of Time Necessary for Response Objectives of 10 ppm and 100 ppm Total Chlorinated Cyclodienes to be Met Via Natural Degradation Assuming a 10-Year Half Life.

Adjacent Surface Waters

Most chlorinated cyclodienes in surface water bodies are in the bottom sediments and are likely in equilibrium with the overlying water. Jordan calculated that the distribution ratio of total chlorinated cyclodienes between sediments and surface waters in the large abandoned dredge pond located to the east of the dump is approximately 100,000.

Fish in the surface waters adjacent to the dump derive contaminants from water, sediment and aquatic biota, including other fish. The relative contribution from each source, and therefore the relative level of contamination, is dependent on the species of fish and is largely controlled by feeding habits.

Water quality criteria define the requisite quality of surface water, and USFDA action levels specify allowable fish levels. USFDA action levels for edible portions of fish and water quality criteria that have been established for the protection of freshwater aquatic biota are not independent entities. The water quality criterion (WQC) for chlordane was derived from the established USFDA action level[7] according to the following relationships:

$$\frac{\text{USFDA action level for edible portion}}{\frac{\text{bioconcentration factor}}{\% \text{ lipid* in whole fish}} \times \% \text{ lipids in edible portion}} = \text{WQC} \quad (1)$$

The bioconcentration factor (BCF) is represented by:

$$\frac{\text{concentration of chemical in whole fish}}{\text{concentration of chemical in water}} = \text{BCF} \quad (2)$$

The relationship between water quality criteria and USFDA action levels permits one to calculate water quality criteria for site-specific conditions if sufficient data are available. In the case of surface waters adjacent to the North Hollywood Dump, response objectives were established for surface water on the basis of water quality criteria (0.0043 ug/l chlordane)[7] and for fish on the basis of USFDA action levels (0.3 ppm chlordane).[8] Chlordane is considered to be an appropriate compound upon which to base a response objective because technical grade chlordane components constitute the majority of chlorinated cyclodienes found in most analyses conducted by TAG.

Because bottom sediments represent a source of contaminants for water and fish, the attainment of response objectives for surface water and fish must ultimately depend on the attainment of a cleanup goal for sediments. The crux then becomes...how clean must the bottom sediment be to attain contaminant concentrations that do not exceed water quality criteria levels in surface water and, in turn, USFDA action levels in fish? The options for cleanup of the sediments in adjacent surface water bodies are:

- Total removal or containment of an appropriate thickness of bottom sediments over the entire area of the contaminated surface water bodies
- Partial removal or containment of bottom sediments based on chemical relationships such as: (1) water quality criteria which link fish quality to water quality and (2) partitioning coefficients for chemicals in coexisting media which links water quality to sediment quality at equilibrium conditions
- Partial removal of contaminants based on results of additional analytical data which focus on those areas that have the greatest degree of contamination

*Lipids are fats or fatlike substances in fish that are capable of solubilizing and storing organic substances such as chlorinated cyclodienes that are ingested by the fish. Different fish species have different percentages of lipid content by weight. Lipids are distributed in the organ cavity as well as in edible flesh. USFDA action levels reflect contaminants present in lipids that are associated with the edible portion (flesh) of fish.

EXPOSURE UNITS (EU) FOR QUANTIFICATION OF RISK FROM CONCENTRATIONS OF DEGRADABLE MATERIALS PRESENT IN SURFACE ENVIRONMENTS ARE CALCULATED ON THE BASIS OF

- CONCENTRATION ABOVE A REFERENCE LEVEL SUCH AS THE RESPONSE OBJECTIVE
- AREA OVER WHICH THE RISK IS POSED
- ANTICIPATED TIME DURATION OF EXPOSURE

SHADED VOLUME REPRESENTS THE QUANTITY OF EXPOSURE UNITS. NUMBER OF UNITS CHANGE FROM TIME A TO TIME B DUE TO NATURAL DEGRADATION.

NOTE: THE CONCENTRATION - TIME PORTION OF THE EU PLOT REPRESENTS A SYSTEM RESPONSE CURVE
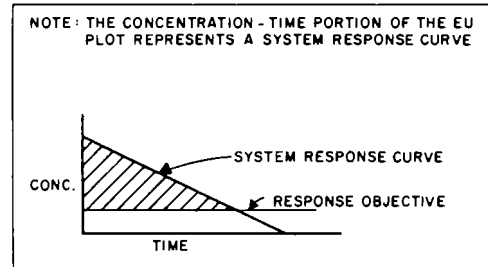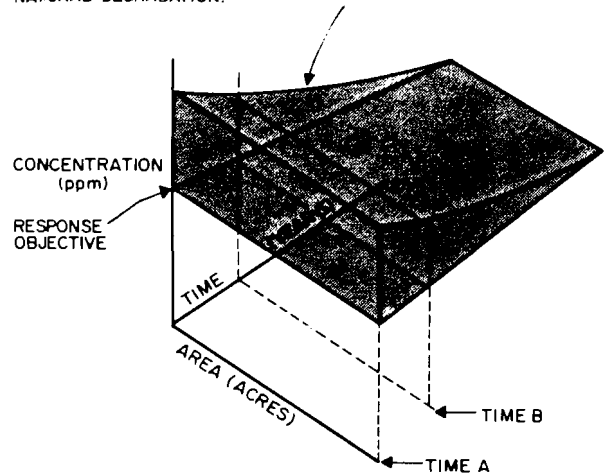
Figure 6
Explanation of "Exposure Units" (EU).

Shallow Groundwater

Shallow groundwater at the North Hollywood Dump represents a potential environmental problem rather than an actual one. Hence, no cleanup goals were established for the shallow groundwater regime.

CORRECTIVE ACTION ALTERNATIVES

In the initial screening of available remedial technologies, the principal criteria used were: (1) applicability to site conditions and (2) reliability/practicality. After the development of corrective action alternatives, an evaluation done of the 41 possible cleanup alternatives was made. The evaluation criteria utilized were:

- Technical feasibility
- Implementability
- Protection of public health
- Protection of environmental quality
- Time to attain response objectives
- Duration and intensity of field monitoring requirements
- Effect on future land use
- Cost [capital, operations and maintenance (O&M) and present worth]

Evaluation of Corrective Action Alternatives

Corrective action alternatives were evaluated for four specific problem areas associated with the North Hollywood Dump: (1) the
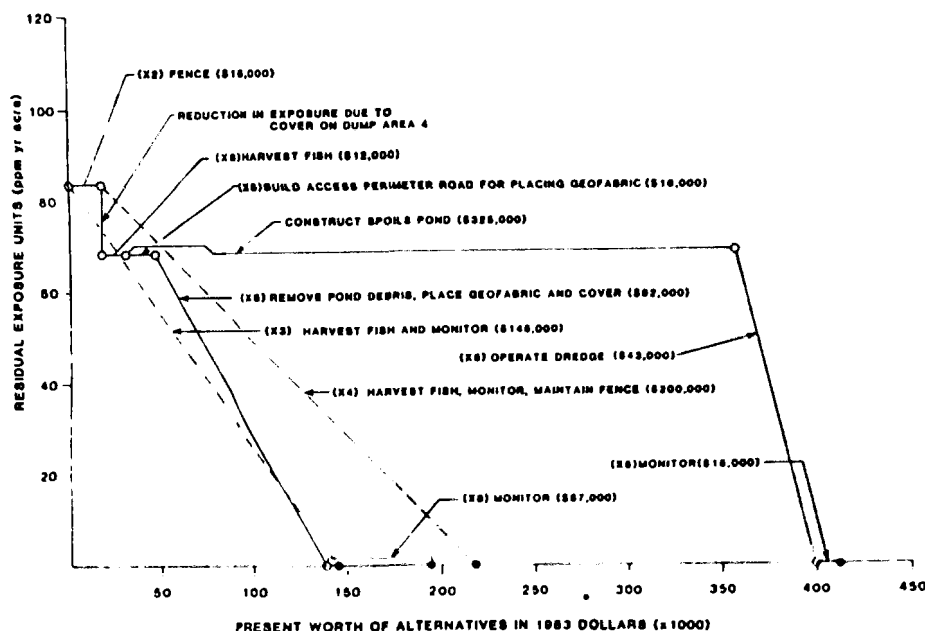
Figure 7
Example of Cost-Effectiveness Diagram for the Various Corrective Actions Identified and Evaluated for the Oxbow Lake

dump itself; (2) the 40 acre abandoned dredge pond located east of the dump; (3) the 0.4 acre beaver pond; and (4) the 2 acre oxbow lake. The alternatives evaluated by Jordan for the dump surface and the oxbow lake are found in Table 1. Alternatives considered for the abandoned dredge pond and the beaver pond are similar in principle in those for the oxbow lake.

The mitigation of contaminants present at the site is dependent on two principal factors: (1) the natural degradation rate of the chlorinated cyclodienes and (2) the quantity of contaminated materials removed or otherwise constrained at the site. A quantitative measure of the relative magnitude of the environmental problems at the site and the potential chemical exposure was developed by Jordan. This measure of exposure, which is referred to herein as "exposure units," constitutes the common basis for measuring the effectiveness of various corrective action alternatives for prob-

Table 1
Corrective Action Alternatives for Selected Problem Areas of the North Hollywood Dump

North Hollywood Dump

• No action
• Fence site until contaminants in surface soils decay naturally to less than response objective
• Cover all surface areas in which contaminant levels are greater than response objective. (Fencing option also considered)
• Cover all surface areas in watersheds on dump contributing to adjacent surface water ponds. (Fencing option also considered)
• Cover entire dump. (Fencing option also considered)
• Remove and dispose of soils in which contaminant levels are greater than response objective

Oxbow Lake

• No action
• Fence lake until contaminants in bottom sediments decay naturally to less than response objective
• Harvest fish periodically until contaminants in bottom sediments decay naturally to less than response objective. (Fencing option also considered)
• Dredge bottom sediments to meet response objectives
• Excavate bottom sediments to meet response objectives
• Cover bottom sediments with clean fill
• Cover bottom sediments with geofabric and clean fill
• Fill pond with clean fill

lem areas (Fig. 6). The quantity of exposure units can be calculated for an area on the basis of:

• Concentration of contaminants above an established reference level such as a response objective
• Area over which the risk is posed
• Anticipated time duration or persistence of exposure

The concept of "exposure units" was utilized in the assessment of cost-effectiveness of corrective action alternatives. Two important aspects of the corrective action alternatives study were: (1) the mitigation of exposure (i.e., the reduction of exposure units) and (2) the cost of alternatives. Plots of cost against exposure units (EU), such as shown in Figure 7, were developed for all the environmental problem areas of the site. The advantage of the cost-EU graphs is that both cost and effectiveness of corrective actions are illustrated simultaneously. Costs are shown as dollars expended, and effectiveness is shown as reduction in exposure. The time factor, i.e., the time required to achieve a reduction in exposure, is not indicated on the graphs.

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RADON CONTAMINATION IN MONTCLAIR AND GLEN RIDGE, NEW JERSEY: INVESTIGATION AND EMERGENCY RESPONSE

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INTRODUCTION

In 1979, the New Jersey Department of Environmental Protection (NJDEP) initiated a program to identify and investigate those locations in the state which were once the site of radium processing facilities. Chief among those sites investigated was a facility in Orange, New Jersey which had ceased operation in the 1920s. Concern over the possibility of off-site disposal of processing waste prompted an aerial gamma radiation survey of surrounding areas of Essex County. This survey identified a number of areas having high gamma radiation; the level and extent of several of the gamma anomalies suggested the possibility of waste disposal. In July, 1983, NJDEP began to investigate two areas of high gamma readings in the towns of Montclair and Glen Ridge. The results of this investigation became available in late November, 1983, and identified a number of homes having unacceptably high levels of radon gas.

On Dec. 6, 1983, the USEPA, acting under the mandates of CERCLA, began immediate removal actions at both the Glen Ridge and Montclair sites. Response actions were taken to reduce the residents' exposure to radon gas and radon progeny. Concurrent with the response action, the USEPA and NJDEP developed and implemented an extensive field investigation to totally assess the extent of the problem.

While radon problems have been identified and addressed in several areas of the country (e.g., uranium mill tailings in the west and phosphate tailings in the southeast), the potential threat posed by radioactive processing material disposed of in densely populated, urban residential communities poses unique problems. In this paper, the authors discuss both the immediate removal actions and the field investigation initiated in response to the problems in Montclair and Glen Ridge.

INITIAL SURVEY ACTIVITIES

In the first quarter of the 20th century, an early radiation industry existed in Essex County, New Jersey. In 1979, the NJDEP began investigating a former radium processing facility (U.S. Radium) site in Orange, New Jersey; the investigation resulted in the site's inclusion on the USEPA National Priorities List for Superfund remedial action.

Historical records showed that this facility operated for approximately ten years (1915-1926) and processed about one-half ton of ore daily. The NJDEP was concerned that such a rate of ore processing coupled with the limited size of the original property might indicate the possible use of nearby non-contiguous areas for disposal of processing waste. At the request of NJDEP, the USEPA conducted an aerial gamma radiation survey of a 12 mi² area surrounding the facility. The resultant isoexposure contour map identified areas of elevated gamma radiation and suggested the existence of several possible areas of waste disposal. The areas were in the towns of Glen Ridge, Montclair and West Orange.

In July, 1983, the NJDEP, after consultation with local officials, began a preliminary investigation of the Montclair and Glen Ridge sites. An initial outdoor gamma radiation survey was conducted in publicly accessible areas. Gamma radiation levels greater than 15 μR/hr (micro-Roentgens per hour), a level approximately twice background, identified properties to be investigated further; permission of owners was then obtained for further surveys of the properties. Affected properties were surveyed using gamma measurements at the surface and at 3 ft above the ground surface. Shallow boreholes were drilled using a hand augur; the gamma radiation in the holes was measured and soil samples were taken for laboratory analysis. In addition, an indoor radiological survey was conducted including indoor gamma measurements and the measurement of radon gas using activated carbon canisters.

The gamma survey and subsurface coring program identified several areas in both neighborhoods in which contaminated material had been disposed. The indoor survey identified a number of houses with radon concentration levels well in excess of the expected background range. Several houses surveyed had levels which exceeded the radon concentration equivalent for radiation workers. The information available was sufficient to indicate that there was an imminent and substantial endangerment to public health and to support the initiation of a CERCLA removal action.

RISK ASSESSMENT AND MANAGEMENT PLAN

The risks associated with exposure to elevated levels of radon gas and radon decay products (also known as "radon daughters" or "radon progeny") have been extensively discussed in the literature. Several sources of information are provided as references to this paper. In brief, radon is a radioactive gas produced by the decay of radium-226, a naturally occurring element. The radon decays into short-lived radon progeny; these progeny are charged particles which may attach to particles in the air. When inhaled and retained in the lungs, the progeny decay further, emitting alpha radiation. The health effect associated with this exposure is an increased risk of lung cancer. Radon quickly disperses in the ambient air; however, in enclosed areas without adequate ventilation, the gas can concentrate, resulting in levels of radon and radon progeny posing a significant risk of increased lung cancer.

In early December, 1983, state and federal public health and environmental officials met to develop a risk assessment and management plan. The results of those meeting were summarized in the

Public Health Advisory for Glen Ridge/Montclair, New Jersey issued by the Centers for Disease Control (CDC).

Specifically, the Health Advisory developed risk estimates for exposure of the residents. Based on a number of sources, the CDC calculated the annual risk of lung cancer for residential exposure to selected radon levels (Table 1).

The risk assessment and management plan also outlined criteria by which all residences sampled would be divided into four categories or tiers based on the extent of the radon problem in the home; the required actions and time frames for immediate removal actions for each tier were also identified. The time frames were established so that no resident was unduly exposed to a risk greater than $1/10^5$ during the response period. The tier categorization is summarized in Table 2.

Finally, the risk assessment and management plan identified the following requirements for further investigation:
• Better define radon and gamma levels in the homes
• Delineate the exact perimeters of radon contamination
• Completely characterize the nature and extent of the source of the radon gas
• Evaluate any potential water contamination
• Assess the level and extent of soil contamination
• Evaluate possible uptake by garden vegetables
• Appropriately evaluate other above-background areas identified in the aerial gamma survey

In summary, the risk assessment and management plan provided a quantification of the potential risk associated with exposure to various levels of radon progeny and also provided overall direction for both the response action and field investigation. This plan was available as guidance to all the affected agencies and the public on Dec. 6, 1983; the day the Superfund removal action commenced.

IMMEDIATE FIELD ACTIVITIES

Confirmation of Radon Progeny Levels

The most immediate concern of the agencies involved in the response action was to better define the radon levels in the homes. The initial radon survey performed by NJDEP utilized activated carbon canisters placed in the residences for three days. These canisters and subsequent analysis on a sodium iodide detector coupled to a multi-channel analyzer measured the concentration of radon gas in picoCuries/Liter (pCi/l) of air.

Since the concentration of radon progeny can vary from house to house due to changes in the percentage of radon progeny in equilibrium with the radon gas, a direct measurement of radon progeny, rather than radon gas, was recommended by NJDEP and the USEPA. To measure radon progeny directly, Radon Progeny Integrated Sampling Units (RPISU) were utilized; these units were developed by Colorado State University and are the primary integrated air sampling system used by the USEPA. In operation, the unit consists essentially of an air pump and a sampling head located outside of the pump housing. The sampling head contains two thermoluminescent dosimeters (TLDs).

During operation, air is pulled through the sampling head, and particulate matter containing the radon decay products is trapped on the filter. The first TLD, located in the airstream directly before the filter, records the alpha energy emitted by the decay of the radon progeny. The second TLD records the ambient gamma radiation which is subtracted from that measured by the first TLD. The units were normally left in place for 5 to 7 days, at which time the sampling heads were removed and the TLDs sent to the USEPA's Las Vegas laboratory for analysis on a TLD reader.

The NJDEP sampling identified 28 homes which had abnormally high concentrations of radon gas. Personnel from the USEPA's Eastern Environmental Radiation Facility (EERF), located in Montgomery, Alabama, conducted the initial, intensive field activity associated with the confirmation testing. USEPA-EERF personnel installed RPISU's in the basements and first floor living areas of each of the identified homes within the first two days of the initiation of the response action; confirmation of the radon progeny

Table 1
Centers for Disease Control Risk Estimates
Annual Risk of Lung Cancer for Residential Exposure to Selected Radon Levels

A) For Continuous LIFETIME Exposure:

Annual Risk of Lung Cancer	Radon Level
1,000 per 100,000	1.0 WL*
100 per 100,000	0.1 WL
30 per 100,000	0.02 WL
6 per 100,000	0.004 WL

B) For a ONE YEAR Exposure:

Annual Risk of Lung Cancer	Radon Level
400 per 1,000,000	1.0 WL
40 per 1,000,000	0.1 WL
8 per 1,000,000	0.02 WL
1 per 1,000,000	0.004 WL

* WL— Working Level—A working level is defined as the potential alpha energy from the short-lived daughters of radon which will produce 1.3 × 10⁵ MEV (MEV = Million Electron Volts) in one liter of air.

Table 2
Categorization of Residences Based on Level of Radon Contamination

Tier	Radon Level	Time Frame	Action (Exposure Reduction)
A	over 0.5 WL	a. immediately (1-2 days)	Restrict occupancy of high level areas of homes to 2 hr/day. Prohibit smoking in high level areas.
		b. within 2 weeks	Temporary remedial action to get as far below 0.5 WL as feasible using temporary measures.
B	0.1-0.5 WL	Prompt (1-3 months)	Temporary remedial action to get to 0.1 WL or less. (Priority of action determined by exposure level.)
C	0.02-0.1 WL	1-2 years	Permanent remedial action to reduce exposure from non-natural source to below 0.02 WL (Priority of action determined by exposure level.)
D	0.02 and below		No action

problem in these homes and the resultant classification of the homes by Tier was attained within the following two weeks. This provided the data required for USEPA and NJDEP to authorize and initiate the design and installation of corrective actions in the most severely affected residences, i.e., Tier A and Tier B homes.

Better Delineation of the Perimeter of Radon Contamination

The identification of a radon contamination problem in Montclair and Glen Ridge was reported widely and extensively by all media, leading to extreme concern on the part of the public; concern that was warranted given the limitations of the investigation at that point. A second major objective of the joint USEPA-NJDEP field investigation was to identify any additional affected residences. In addition, efforts were made to determine the extent of the radon contamination problem by establishing a boundary around the study areas beyond which there were no affected residences. To achieve this goal, a sampling program based on grab sampling and RPISU monitoring was designed.

Grab sampling techniques measured the radon daughter product activity captured on a filter over a 5 min sampling period. The filters were transported to a mobile laboratory for immediate analysis using alpha radiation detectors. Two grab sampling techniques were utilized: the Kusnetz method and the Thomas modified Tsivoglov method.

The CDC Health Advisory provided the following guideline for radon concentrations in homes; "...The current USEPA limit for radon levels in dwellings is 0.02 WL, which is at the higher end of the range of natural background levels found in homes in the United States. Houses in the United States normally range from less than 0.002 WL to 0.04 WL, depending upon site of construction. Natural background levels above 0.01 WL are infrequent..." This guideline served as the basis for formulation of the sampling program.

A major premise of the study was that grab sampling could be utilized as a proxy to the more time-consuming RPISU sampling. In order to be conservative, samples were generally taken in the basements of the residences, the area of expected highest radon concentration. Furthermore, as an added measure of conservatism, a grab sample value of 0.01 WL was used to determine the need for subsequent RPISU sampling for 5 to 7 days. A RPISU value of 0.02 WL or greater, in turn, was used to define the need for corrective action. A schematic of the sampling program is shown in Figure 1.

The reliability of the grab sampling methodology for determination of indoor radon progeny levels in Montclair and Glen Ridge was assessed by staff from the USEPA's Office of Radiation Programs.[1] An examination of unpublished data from an 18-month USEPA instrument comparison project in Butte, Montana, showed that only 2.1% of 608 grab samples exhibited values of less than 0.01 when the actual annual level was above 0.02 WL, and only 0.23% of 435 samples exhibited levels of less than 0.01 WL when the actual annual level was above 0.03 WL.

The grab sampling program began with the establishment of sampling sectors; 13 sectors were eventually established in Montclair and 15 in Glen Ridge. Sectors consisted of 10-15 homes grouped around a central point where a mobile laboratory could be stationed during analysis. In addition, grab samples outside of the

sectors were taken when requested by residents or by design if a location outside of the sector would aid in establishing the desired boundary. Grab sampling was performed by USEPA-EERF personnel throughout December and was continued by members of the USEPA's Field Investigation Team (FIT), NUS Corporation, in January and February. Eventually, over 500 homes were sampled (Table 3). The affected areas and the perimeter of affected homes are shown in Figures 2 and 3.

Table 3
Radon Progeny Sampling Summary
(March 26, 1984)

Tier	# of Homes Inside Sectors	# of Homes Outside Sectors	# of Homes Total
A	2 (Montclair)	0	2
B	14 (8-Montclair) (6-Glen Ridge)	0	14
C	25 (15-Montclair) (9-Glen Ridge) (1-West Orange)	0	25
D	309 (83-Montclair) (165-Glen Ridge) (36-West Orange) (25-East Orange)	161 (64-Montclair) (76-Glen Ridge) (17-West Orange) (4-East Orange)	470
Total Residences Monitored	350 (108-Montclair) (180-Glen Ridge) (37-West Orange) (25-East Orange)	161 (64-Montclair) (76-Glen Ridge) (17-West Orange) (4-East Orange)	511

Figure 1
Flow Chart—Radon Sampling Project
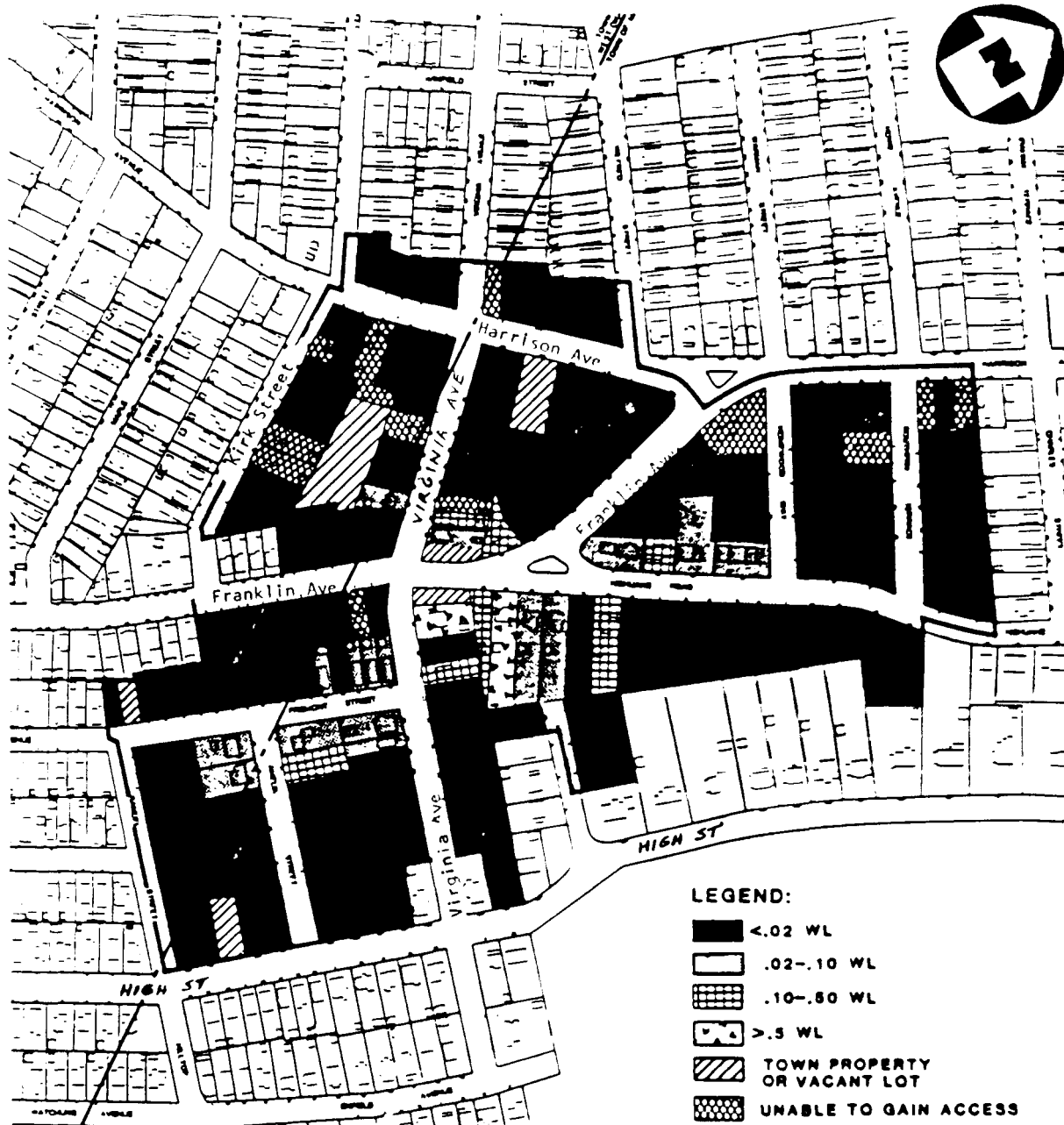
Figure 2
Summary of Results of Indoor Radon Sampling
(Montclair Site, Montclair, NJ)

IMMEDIATE RESPONSE ACTION

Implementation of Corrective Actions

The design of corrective actions in Tier A and B homes was initiated immediately upon confirmation of tier status by RPISU sampling. The USEPA Region II Technical Assistance Team (TAT) contracted the Arix Corporation of Grand Junction, Colorado to design and implement the corrective action.

In the last decade, a number of different remedial techniques have been developed for reducing the concentration of radon gas and radon progeny in homes; these techniques, discussed extensively in the literature, include the sealing of cracks and crevices to reduce radon migration into the homes, the use of passive systems such as the construction of subsurface ventilation systems to intercept and reroute the radon before it enters the home and the use of active systems such as the installation of electrostatic precipitators to remove particulate matter from the air. However,

given the high levels of radon in the residences in Montclair and Glen Ridge and the need to implement a corrective action that would be guaranteed to be successful, a very conservative approach to the problem was taken.

Fresh air ventilation systems were designed and installed in the basements or crawlspaces of all affected homes. These systems pumped outside air into the homes at a rate averaging 200 ft³/min, diluting the indoor air before being vented through louvers or exhaust fans. Individual electric heating units were included as a component of each ventilation system and were designed to heat the outside air to approximately 65 °F before being introduced into the homes. Separate electrical circuits and meters were installed to allow direct billing of system operation and maintenance costs to the State of New Jersey's Spill Fund.

Ventilation systems were installed in 22 homes during the response period. These systems are considered a temporary measure, designed to reduce the concentration of radon and radon
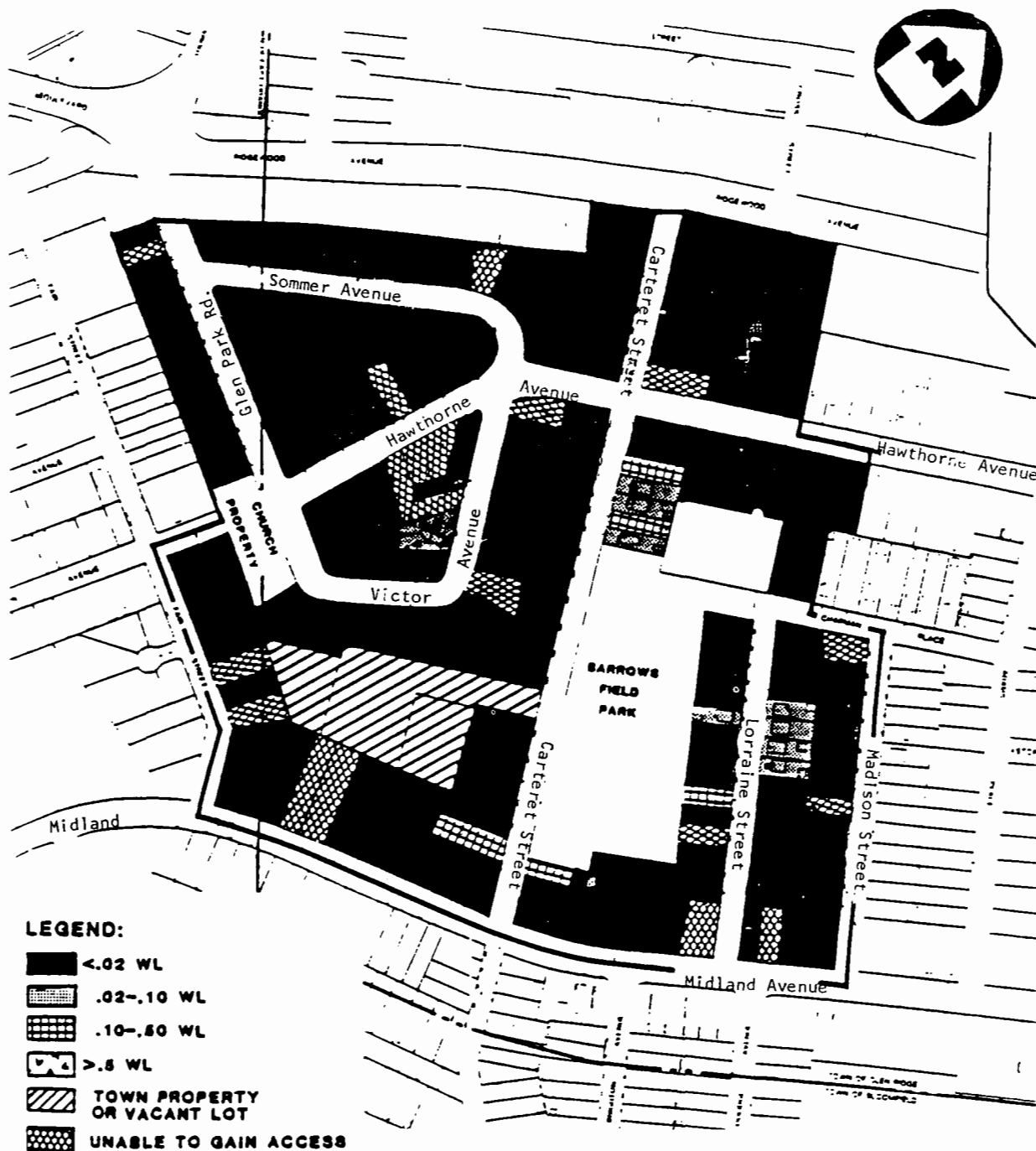
Figure 3
Summary of Results of Indoor Radon Sampling
(Glen Ridge Site, Glen Ridge, NJ)

progeny in the home until a permanent remedial solution can be implemented. The systems have been successful in reducing the concentration of radon progeny in the Tier A and B homes to Tier C levels or lower. The concentrations of radon gas and radon progeny in selected homes before and after installation of the ventilation systems are shown in Table 4.

Post-remedial monitoring continues on a quarterly basis to ensure that the systems are operating properly. In addition, Tier C homes are monitored quarterly to ensure that the radon progeny levels have not changed. In several instances, the quarterly monitoring identified Tier C residences as having Tier B levels of radon progeny. These homes, once identified, were immediately scheduled for installation of ventilation systems.

Installation of ventilation systems in all identified Tier A and B homes was completed in early April, 1984, thus meeting the directives of the CDC Health Advisory.

ADDITIONAL FIELD INVESTIGATION ACTIVITIES

Source Characterization Study

A number of other field activities were initiated to more fully assess the extent of the problem.

As an initial step, the New Jersey Geological Survey conducted a review of historic photos and maps to identify areas where contaminated material may have been deposited. The review identified a number of areas where excavation or filling of material may have occurred; several large areas were occupied by residences showing radon contamination.

After the historical review, a program was developed to characterize the general nature and extent of the material believed to be the source of the radon gas. This investigation was conducted

Table 4
Reduction of Radon and Radon Progeny in Remediated Residences

	Pre-Remediation		Post-Remediation				Radon % Reduction
	Radon Progeny (Working Level)	Radon (pCi/L)	Radon Progeny (Working Level) #1	#2	#3	Radon (pCi/L)	
Residence A							
Basement	0.201	110.4	0.010	0.012	0.006	14.2	87
First Floor	0.287	80.6	0.021	0.027	0.005	10.3	87
Second Floor	NA	85.3	NA	NA	NA	9.4	89
Residence B							
Basement	1.549	440.0	0.001	0.004	-----	0.4	99
First Floor	0.170	50.0	0.001	0.005	-----	0.5	99
Second Floor	NA	132.0	NA	NA	-----	0.5	99
Residence C							
Basement	0.204	102.0	0.044	0.081	0.017	36.1	65
First Floor	0.256	83.8	0.026	0.153	0.034	26.8	68
Second Floor	NA	92.6	NA	NA	0.044	25.4	73
Residence D							
Basement	0.505	186	0.014	0.004	-----	10.0	95
First Floor	0.466	112	0.042	0.005	-----	17.8	84
Second Floor	NA	120	NA	NA	-----	14.1	88

NA=Not Available

by the Region II Field Investigation Team, NUS Corporation, and consisted of an extensive outdoor surface gamma survey using Micro-R meters at a height of 3 ft above the ground followed by a subsurface investigation into those areas evidencing surface gamma anomalies. For consistency, an attempt was made to survey all properties included in the radon monitoring sectors. Eventually, 209 properties in both study areas were surveyed. Significant surface gamma anomalies were investigated further by drilling boreholes: 326 boreholes were drilled in the neighborhood. The level of gamma radiation in all boreholes was determined using a scintillometer to measure the vertical extent of contamination. Soil samples were taken and analyzed using gamma spectrometry to fully characterize the contaminated material.

The result of the study identified the source of the contamination as concentrated Radium-226. It became clear that the material had been used as fill for grading purposes. It averaged 5 ft in depth but was generally no deeper than 10 ft. The material was concentrated in four large areas with scattered discrete pockets close-by. The volume of material requiring removal was estimated to be approximately 20,000 yd³. The locations of the contaminated material in Glen Ridge and Montclair are shown in Figures 4 and 5.

Indoor Gamma Radiation Surveys

All Tier A, B and C homes were subjected to two indoor gamma surveys. The first was an exposure level survey conducted by USEPA-EERF personnel to establish whether residents were being exposed to excessive levels of gamma radiation inside their homes.

In this survey, the engineers utilized scintillometers and pressurized ionization chambers (PIC). In addition, a procedure called a delta gamma survey was performed. In this survey, one uses detection equipment to measure relative differences in the gamma radiation emanating through the walls and floors of the residences; it was utilized to ascertain the location of contaminated material under and against the foundation of the home. The results of these surveys were represented graphically on floor plans for each home.

Groundwater Monitoring Program

The CDC Health Advisory also recommended that the potential for groundwater contamination be fully evaluated. Immediately upon the discovery of the problem, all public water supply wells in the area were sampled for radionuclides; none showed any concentration in excess of standards. There were no private wells in the area.

Subsequent to the completion of the source characterization study which identified the area where the contaminated material was located, a program was developed to ascertain the presence of radionuclides in the major groundwater systems in the area. This program, currently ongoing, entailed the installation of groundwater monitoring wells in unconsolidated surface deposits to monitor localized groundwater and in the underlying bedrock formation to monitor regional groundwater flow.

SECONDARY RISK ASSESSMENTS

Evaluation of Gardening

A major public concern after discovery of the problem in Montclair and Glen Ridge was the threat posed by ingestion of garden vegetables grown in the study area. The NJDEP's Bureau of Radiation Protection conservatively estimated the potential for uptake and ingestion of radionuclides. After consultation with CDC and the USEPA's Office of Radiation Programs, the conclusion was reached that, given the non-uniform and limited existence of highly contaminated homes, the health risks from ingestion of vegetables grown in radium-contaminated soils did not warrant a general recommendation that residents discontinue gardening. However, for those locations where the concentration of radium in the soil was known to exceed 100 picoCuries per gram (pCi/gm) residents were advised to discontinue extensive gardening.

Evaluation of the source characterization study identified very few gardens located in any area with elevated gamma radiation; where this occurred, the residents were so advised. NJDEP offered assistance in locating gardens and also offered to analyze any vegetables which may have been grown the previous year and canned or home processed.

Evaluation of Gamma Radiation Levels

The CDC evaluated the surface and indoor gamma radiation levels in Montclair and Glen Ridge. Based on this review, there was no need for a recommendation that access to any area be restricted to the general public in any way. In addition, the CDC developed a method to estimate, in a conservative manner, the annual dose to a

Figure 4
Soil Removal Map (Montclair Site, Montclair, NJ)

resident due to exposure to gamma radiation. This method assumed that the residents spent the entire year confined to their property, 18 hr indoors (8 hr in the bedroom, 5 hr in the living area, 5 hr in the basement) and 6 hr outdoors. The highest gamma reading in each room was utilized in calculating potential exposure; outdoors, a weighted average based on distribution of contamination was used.

Based on these calculations, no resident living on any of the properties in the study area would exceed the regulatory limit of 500 mrem/yr for doses to an individual in the general public. Nevertheless, any residents whose calculated dose approached the limit, even with the conservative assumptions utilized, were advised of steps that could be taken to reduce their exposure. In addition, residents were provided with both outdoor maps and floor plans of their property showing the gamma levels and highlighting any area where the gamma readings were higher than 60 μR/hr, the gamma radiation level that would result in an annual exposure of 500 mrem/yr if occupied continuously.

PUBLIC INTERACTION

The announcement of the discovery of radioactive material in residential communities resulted in extreme public concern, especially since the magnitude of the problem was not known at the time of the announcement and could not be known without the planned extensive field investigation. To attempt to educate, inform and reassure the public, an extensive program of public interaction was developed. A combination command post and information center was established in the Montclair Municipal Building, and the telephone numbers were widely publicized.

During the first several weeks of the project, state and federal staff averaged two meetings every day with township officials, school boards, affected homeowners and the general public. All efforts were coordinated with the local health departments, which provided extensive support in reaching the public. In addition, the Township of Montclair formed a task force of local citizens which proved extremely helpful in disseminating information and expressing the concerns of the populace.

The grab sampling program was explained at every opportunity, and the citizens were informed as to the day the sampling teams would be in their area. This often led to residents providing keys to their neighbors or arranging to be home during that time; this was crucial to the success of the grab sampling effort.

Individual access forms were obtained from homeowners prior to the gamma survey; if drilling on that property was required, the homeowner was contacted in advance of the drilling date.

When homes were identified as Tier A or Tier B, thus requiring corrective action, teams of federal, state and contractor personnel met with the homeowners to explain what was to occur and to address any concerns.

The request heard from the public most often was for the timely release of data, especially the indoor radon monitoring results. With this in mind, NJDEP and the USEPA attempted to contact the homeowners by telephone whenever indoor data were available. In the case of the grab sampling results, this often occurred on the same day as the sampling. RPISU results for the longer sampling period were also transmitted by telephone upon receipt from the laboratory. All indoor results were confirmed by the NJDEP in writing to the homeowner.

Figure 5
Soil Removal Site (Glen Ridge Site, Glen Ridge, NJ)

Upon completion of the field investigation, all residents who had work performed on their property received a file containing all pertinent information, specifically, indoor radon results, indoor gamma radiation levels, outdoor gamma radiation levels and the location of any contaminated material. Given the highly technical nature of the data, the USEPA and NJDEP personnel were available on several evenings and Saturdays to meet with individual homeowners to review and explain their information.

CONCLUSIONS

Responding under the emergency provisions of CERCLA, the USEPA and NJDEP have reduced the exposure of the affected residents to radon gas. In addition, other potential health risks have been assessed. Moreover, the source of the contamination has been identified. This allows the agencies to plan for and pursue a more permanent solution, such as the removal of the contaminated material to an off-site location.

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LESSONS LEARNED IN THE CONDUCT OF REMEDIAL ACTION ACTIVITIES

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INTRODUCTION

In response to the threat to human health and the environment posed by uncontrolled hazardous waste sites, a variety of civilian and military remedial action programs have been implemented. Prominent among these are the Installation Restoration Program (IRP) and the Environmental Restoration Defense Account (ERDA) managed by the Department of Defense (DOD) and the Superfund Program (CERCLA) and Resource Conservation and Recovery Act (RCRA) managed by the U.S. Environmental Protection Agency (USEPA).

Cleaning up hazardous waste sites is a new field in science, engineering and public policy. Consequently, little data are readily available on the performance and costs of remedial technologies and on management of site cleanups. Although the remediation activities conducted by DOD, the USEPA and private sector companies are similar in nature, there is usually no formal coordination effort for transferring technology or lessons learned from one agency to another. In addition, there is usually no formal mechanism for intra-agency transfer of technology. Indeed, the technology transfer that does occur is often a random happenstance process based on word-of-mouth documentation.

In response to this apparent communications gap, the U.S. Army Engineer Waterways Experiment Station (WES) conducted a survey of Federal, state and private sector personnel with experience in the conduct of remediation activities. The primary purpose of the survey was to compile a comprehensive problem-solution data base that could be used by project personnel in the conduct of future remediation activities. Over 150 individuals with first hand experience in the administration design and construction of remedial action projects were contacted during the course of the survey.

Although the survey identified over 125 individual lessons learned, because of space limitations, only the 17 most significant are presented in this paper. For organizational purposes, the lessons learned presented below are categorized into the two basic steps associated with implementation of a remedial action: planning and design and construction.

PLANNING REMEDIAL ACTIONS

Recognizing Technological Limitations

Problem: In some cases, the technology needed to handle the total cleanup of a site may not exist. For example, where contamination of a subsurface aquifer has occurred, it may be impossible to flush all contaminants out of the porous geologic units simply because of the limited access any flushing agent has to pore space in the units. In other instances, the reactions (adsorption, precipitation, etc.) used to remove a contaminant from surface water may not be efficient enough to restore the water to its precontamination condition.

Solution: Misconceptions about the existence of available technology and its associated capabilities are common among laymen as well as within the engineering community. Engineers concerned with the planning and design of remedial investigations and design must be aware of available technologies and particularly the limitation of technologies. This awareness can be developed through the implementation of formal training programs. Training can be accomplished on an individual basis or in organized classes. Advantage should be taken of the many training opportunities available in the private sector. Further, it should be recognized that technologies in this area are rapidly changing. As a result maintenance of an adequate level of competence can only be accomplished by the conscientious efforts of individuals.

Establishing Cleanup Criteria

Problem: Establishing cleanup criteria, i.e., "how clean is clean" has proved to be one of the most difficult problem areas that must be resolved. In many cases, there are no firm guidelines or regulations limiting levels of specific pollutants in the environment. Contamination limitations are usually established on a case by case basis in consultation with appropriate local, state and federal regulatory agencies.

Solution: To date, the "how clean is clean" problem has not been resolved. The USEPA is currently addressing the problem and is attempting to develop risk-based guidelines for maximum allowable contaminant concentrations. Until appropriate criteria are established, site cleanups must continue to be addressed on a site specific basis. The extent of cleanup will depend on the hazard posed by the site as judged by four major factors: (1) nature of the waste, (2) dispersal pathways, (3) receptor characteristics and (4) site management.

In most cases, restoration of a site to a state equivalent to its precontamination condition will not be practical. The relationship between cost and cleanup is an ever-steepening curve with the final steps to 100% restoration the most expensive. The level of restoration will usually be balanced against the cost of restoration at the point where immediate adverse effects to the surrounding environment are eliminated and long-term releases and dangers from bioaccumulation of contaminants are controlled at some low level. Many sites may never reach a state of restoration where the land

can be designated for unlimited use. In extreme cases, on-site contamination may remain at levels that require indefinite restricted access to the site.

Treatment Process Development

Problem: In some cases, it may be necessary to collect and treat hazardous wastes or contaminated materials. A variety of treatment processes are available for specific applications. Planners and designers of a remedial action project may be relatively inexperienced in the selection and application of hazardous waste treatment processes.

Solution: Planners and designers must either develop some expertise in the treatment of hazardous waste or such expertise must be obtained from outside sources. It should be remembered that there is only limited experience with many processes being applied to the treatment of hazardous waste. For this reason, outside consultants and contractors are also limited in their experience with various hazardous waste treatment processes. As a result, the consultant should be questioned thoroughly and several different opinions should be solicited from as many sources as practical.

Use of Industrial Specialists

Problem: Although the typical remedial action project is designed as a construction project, there are many facets of remedial action projects that are more appropriately handled by other than engineering personnel. Examples include industrial hygienists, industrial specialists, toxicologists, fire prevention and protection experts, chemists, etc. Planners and designers are often reluctant to admit a lack of knowledge and have not effectively used sources of specialized expertise.

For example, after the award of a remedial action contract at one Superfund site, a representative of an electric utility was brought to the site to discuss the possibility of PCB contamination in electrical components other than transformers. After extensive discussions with the specialist, it was determined that additional pieces of electrical equipment on the site which had not been tested for PCB fluids might contain PCBs. If this information had been known at the time of the design, the contract could have been written differently and the cost of removing the PCB-contaminated components from inside the other electrical items could have been included in the basic contract rather than in a change order as ultimately required.

Solution: Planners, designers and constructors should be trained to recognize the need for specialized areas of expertise during all phases of the remedial action project. The input of specialists should be incorporated into the design process as early as possible.

Limited Knowledge of Regulations

Problem: Engineers responsible for planning remedial action projects are often relatively unfamiliar with laws, regulations and procedures. Furthermore, local, state and federal requirements may conflict. For example, federal regulations define transformers as uncontaminated if PCBs are less than 50 ppm. Thus, under federal requirements these transformers can be landfilled at any approved non-secure landfill. However, some states (Pennsylvania, for example) do not allow any transformers to be disposed of in the State. Thus, on one Superfund project noncontaminated material had to be transported out of state to a secure landfill at substantially increased cost.

Solution: Planners and designers must be thoroughly familiar with all applicable laws, regulations and procedures. This familiarity must extend to local, state and federal requirements. Selected remedial action alternatives must meet the most stringent requirements. Conflicts in regulations and laws must be resolved early in the planning process. Where uncertainty exists, regulatory agencies should be consulted for interpretation of requirements. It should be noted, however, that USEPA interpretation of regulations tends to be non-uniform.

Permits, Licenses and Approvals

Problem: Failure to recognize the major time constraints that may be involved in obtaining necessary permits, licenses and approvals can cause extensive time delays.

Solution: It must be recognized that the time from project formulation to project implementation may be significantly increased by the necessity to obtain appropriate permits and approvals from local, state and Federal regulatory agencies. The exact nature of required permits, licenses and approvals will depend on the characteristics of the site, location of the site and type of remedial action selected for implementation. All permits, licenses and approvals should be obtained prior to start of the remedial action. Although little can be effectively done to speed up the regulatory process, a detailed knowledge of required approvals will prevent unnecessary delays once on-site work is initiated.

Community and Public Relations

Problem: The importance of community relations during all remedial activities cannot be overstressed. Good community relations can ensure that a project will proceed smoothly and efficiently from start to finish. Poor community relations can result in project delays, increased costs and residual resentment in the community. Engineering personnel tend to think of hazardous waste sites as a purely technical problem and do not understand the importance of good community relations.

Solution: Abandoned hazardous waste sites and spills of hazardous materials are not simply a technological problem, but also have political, economic, psychological, social and human health impacts as well. There are good reasons why people are likely to be highly concerned about hazardous waste problems and proposed cleanup efforts. Unless community relations are arranged with care and skill, there can be a tense, agitated public looking for help, but unsure where to turn and likely to be suspicious of any response that seems to be half-hearted.

Recognizing that hazardous waste sites are more than just a technical concern, the USEPA has developed community relations guidance based on the experiences of USEPA regional offices in handling both hazardous waste remedial action projects and hazardous materials spills. Interim community relations guidance has been issued requiring development of a community relations plan for all hazardous waste sites where Federal funds will be spent for more than two weeks.

The plans require that a substantial level of effort be devoted to interacting with local communities at each site. The amount of interaction is determined by projecting both the degree of citizen concern and the environmental problem at the site. The more visible and serious the hazardous waste site, the more active the community relations program should be.

The USEPA attempts to handle the concerns and expectations of local communities with foresight, care and compassion. The primary purpose of implementing a community relations policy is to assure that actions at hazardous waste sites are understood, accepted and supported by local communities that may be affected by the site. The policy stresses the importance of carrying out cleanup actions without disrupting the normal life of the community.

A well thought out program of community relations is an integral element of any strategy to achieve cost effective solutions at remedial action sites. The problems at some hazardous waste sites may be difficult to understand and occasionally frightening to the uninformed. Unless the concerns of communities affected by the site are understood and addressed, it is possible that resulting misunderstandings will cause long delays and cost overruns.

Statements to the Media

Problem: Remedial action investigations and projects attract the attention of the media. From time to time, both government and contractor personnel will be requested to make statements to the

media. Comments delivered in jest to relieve the tension of a particularly hazardous operation or off-hand comments not based on fact may lead to unnecessary concern on the part of the media and a sensational story. For example, when asked how he would handle shock sensitive material, one contractor replied, "...we will treat it just like nerve gas...." A poor analogy because the only words the press ever heard were nerve gas.

Solution: Statements to the media should follow the simple rule: "Be careful what you say and say what you mean." If at all possible, avoid dealing directly with the press. A Public Affairs Officer (PAO) should be on-site whenever reporters or media are present or expected. If the press contacts you, first refer them to the PAO for information. For support on technical questions, the PAO should have a technical representative participate in press interviews.

DESIGN AND CONSTRUCTION OF REMEDIAL ACTIONS

Contractor Responsiveness

Problem: The conduct of remedial action projects requires special equipment and, more importantly, special skills by contractor personnel. It is obvious that it is in the best interest of all concerned to utilize only competent contractors. The problem is in determining how contractor competence will be judged.

Solution: The contractor's competence is usually judged from the bidding documents received. In addition to traditional bid documents (bid form, bid bond, performance bond, etc.), the bidding documents on several Superfund projects have required the bidder to submit the following additional information with his proposal: the contractor's prior experience in removal of hazardous wastes, the qualifications of the contractor's personnel who will perform the work, the contractor's equipment that will be available for performing the work, agreements with transporters to haul the hazardous waste and agreements with disposal sites to handle the various hazardous wastes. These documents are used to determined the responsiveness of the bidder.

The use of these documents is illustrated in the following example from a Superfund project. The disposal site for waste material containing greater than 500 ppm of PCB proposed by the two lowest bidders was only licensed to store the material. Contract documents required that all waste material be shipped directly to the site of final disposal. The two lowest bidders were declared to be non-responsive. The lowest bidder challenged this decision. The court upheld the original decision. A better scheme for ensuring the competence of contractors is to prequalify all bidders.

Contractor Pre-Bid Site Access

Problem: A contractors pre-bid access to the site will probably be limited to any pre-bid conferences. Such limited site access makes it difficult for the contractor to develop a reasonable understanding of project complexities and may result in high bids based on the contractors uncertainties.

Solution: Aerial or typical ground level photographs of the site should be included in the bid documents. Care should be taken to ensure that selected photographs are representative of site conditions. Appropriate disclaimers should be placed on the photographs so that the final interpretations are the contractors'.

Utility Relocation

Problem: Potential remedial action sites may contain various utility services such as telephone, power, water and sewer lines. These utilities may serve the site or merely pass through the site on utility easements. Utility companies may be slow to relocate services resulting in potential project delays and added project costs for the relocation. The response of utility companies may be particularly slow at remedial action sites.

Solution: The site should be inspected by project designers early in the remedial investigation process. Particular attention should be given to identifying utilities that may require relocation. The identification of underground utilities is especially important. This determination of utility corridors can be accomplished by either on-site inspections or review of old maps, plans, etc. Once utility services have been identified, coordination with utility companies should be initiated as soon as practicable. Required utility relocations can be accomplished by the remedial action contractor or by the utility. The nature of the site (degree of hazard) will probably determine the manner in which the relocation is accomplished. The decision should be made in consultation with the appropriate utility companies.

Project Phasing and Scheduling

Problem: Climate and weather conditions may severely impact the conduct of remedial action activities. Projects have been delayed by the designer's failure to consider these factors. This problem may be particularly acute in those areas of the country where it is customary to shut down construction projects during winter months. For example, at one remedial action project the waste treatment plant had just been started when the contractor assumed that it was time to shut down for the winter; project designers had assumed that the contractor would work through the winter. In addition, summer heat will slow down all operations that must be performed in protective clothing.

Solution: Since remedial action projects are generally designed as a series of construction activities, the potential impacts of climate and weather related factors must be incorporated into the project planning process. Project designers must be aware of local (site specific) weather and climatic characteristics and develop project schedules accordingly. The phasing of work and how the time of year will affect work schedules must be considered. In addition to climate and weather, consideration must also be given to such cyclic factors as inundation by flood waters.

Split Contracts

Problem: Large projects may be divided into phases with different contractors responsible for various phases of the project. A typical example from the Superfund Program is the use of one contractor for initial site cleanup, inventory of waste materials and repackaging of any hazardous materials found to be contained in deteriorated drums or packages. A second contractor may be used to load and haul the materials to the final disposal site. As a result, there may be extensive duplication of effort in testing to determine what materials are being handled. The split responsibilities between contracts resulted in time delays and a split in the responsibility for ultimate disposal of the waste.

Solution: Where possible, all construction activities associated with the remedial action should be accomplished under a single contract. The prime contractor should have sole responsibility for completion of the remedial action from initial site organization to ultimate disposal of the waste materials. Subcontractors may be used by the prime contractor; however, the government should have a single point of contact with the prime contractor. If it is necessary to have more than two contractors on-site at the same time, they should work for the same agency.

Inadequate Design Development

Problem: Several remedial action alternatives are quasi-experimental in nature, i.e., they have not been fully field tested. In many cases, the selected alternative attempts to go directly from the laboratory to the field. Problems of this nature seem to be particularly acute if the solidification/stabilization alternative is selected. Although the solidification/stabilization alternative has been used extensively, the actual chemistry of solidification/stabilization technology remains more art than science. Several problems have been reported with field scale solidification/stabilization, primarily concerns over the adequacy of reagent mixing and the potential fire and/or explosion problem if reactive solidification/stabilization reagents are added with incompatible wastes. Two minor explosions and fire incidents with resultant evacuations have been reported on remedial action projects. Both of these incidents were related to the use of quicklime (calcium oxide) and the heat gen-

erated during the hydration process when quicklime is added to a liquid or sludge.

Solution: Remedial action alternatives incorporating the addition of chemical reagents should be fully evaluated in the laboratory and field environment. Particular attention must be given to potential heat of reaction problems when reactive chemicals are to be added to the waste. The potential for explosion, fire and release of volatile organics should be evaluated. The scenario selected for field scale addition of the solidification/stabilization reagents should be subjected to full scale testing with actual construction equipment. Problems should be identified and corrected prior to initiating the contract for site cleanup.

Extent of Hazard Revision

Problem: As a project progresses, the extent of hazard associated with a specific site is subject to change. The degree of actual hazard may increase or decrease.

Solution: A preliminary judgment of the extent of hazard is generally made on any hazardous waste site selected for remedial action. As additional data become available, the hazard assessment should be updated based on new field and laboratory data. Contract provisions should allow for changes in the level of hazard. Revised hazard estimates may be used to adjust safety planning and to refine designs for treatment and/or containment.

Health versus Safety

Problem: As the required level of personal protection increases, health and safety requirements may conflict. Heavy equipment operation may be particularly hazardous at high levels of personal protection. It has been suggested that real heavy metal contamination is when a D-8 bulldozer or 20-ton dump truck runs over you.

Solution: Remedial action activities should be conducted at the lowest possible level of protection consistent with both health and safety concerns. Sound judgment must be utilized to evaluate the trade-offs between increased personal health protection and increased safety hazards created when equipment operators are required to wear such equipment. Two examples of this concept are: at low contaminant levels, full face masks for heavy equipment operators may not be justified since they hinder their vision; respiratory protection may not be necessary for truck drivers if they are required to remain in their trucks.

Hazardous Waste Manifest

Problem: Remedial action alternatives may include excavation and/or removal and off-site disposal of hazardous waste materials.

Off-site disposal options require the preparation of a Hazardous Waste Manifest. Under RCRA, an individual, firm or agency must be identified as the generator, thus accepting responsibility under the requirements of RCRA for the waste even after it is disposed of in a secure landfill. Several Superfund projects have specified that the remedial action contractor sign the manifests as the generator. Understandably, contractors are reluctant to sign these "Hazardous Waste Manifests" as the generator because of the inherent liabilities. Project delays may result because of confusion over this point.

Solution: The person, firm or agency that will sign the "Hazardous Waste Manifest" must be clearly defined in the bid documents. The designated generating agency must have an on-site representative during the accomplishment of the remedial action. If the "performing agency" is different from the designated "generating agency," the "generating agency" may wish to designate the "performing agency" as its agent for purposes of signing required manifests.

CONCLUSIONS

When reviewed in retrospect, many of the lessons learned as a result of this study appear to be "common sense" items. However, each of the problems identified during this survey actually occurred, with many resulting in significant project delays and cost increases. The lessons learned data base for the conduct of remediation activities is increasing as the number of completed remedial action projects increases. The development of the level of expertise required for efficient conduct of remediation activities can only be accomplished if the lessons learned by individuals are documented in a manner providing ready access to the relevant data without an undue expenditure of resources.

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FEASIBILITY STUDY FOR BURIED ARSENIC WASTE AT PERHAM, MINNESOTA

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BACKGROUND

In the 1930s and 1940s, the U.S. Department of Agriculture used arsenic as a pesticide to control grasshoppers. The State of Minnesota provided mixing stations, storage areas and distribution points for the grasshopper bait, one of which was in Perham. When the program was discontinued, leftover arsenic (most likely in the form of crude arsenic, arsenic trioxide, and sodium, calcium or lead arsenate) was buried at a depth of about 7 ft at the Perham fairgrounds.

The Perham arsenic burial site is located in Otter Tail County, Minnesota, at the southern edge of the town of Perham (Figs. 1 and 2). The site, which lies between a county fairgrounds cattle shed and the Hammer's Construction building, is a fenced area with dimensions of approximately 40 ft × 100 ft. A state highway is located about 30 ft west of the site.

Soil and groundwater in the immediate vicinity of the buried waste are contaminated with arsenic. Arsenic concentrations in soil samples taken from five locations in the trench range from 150 to
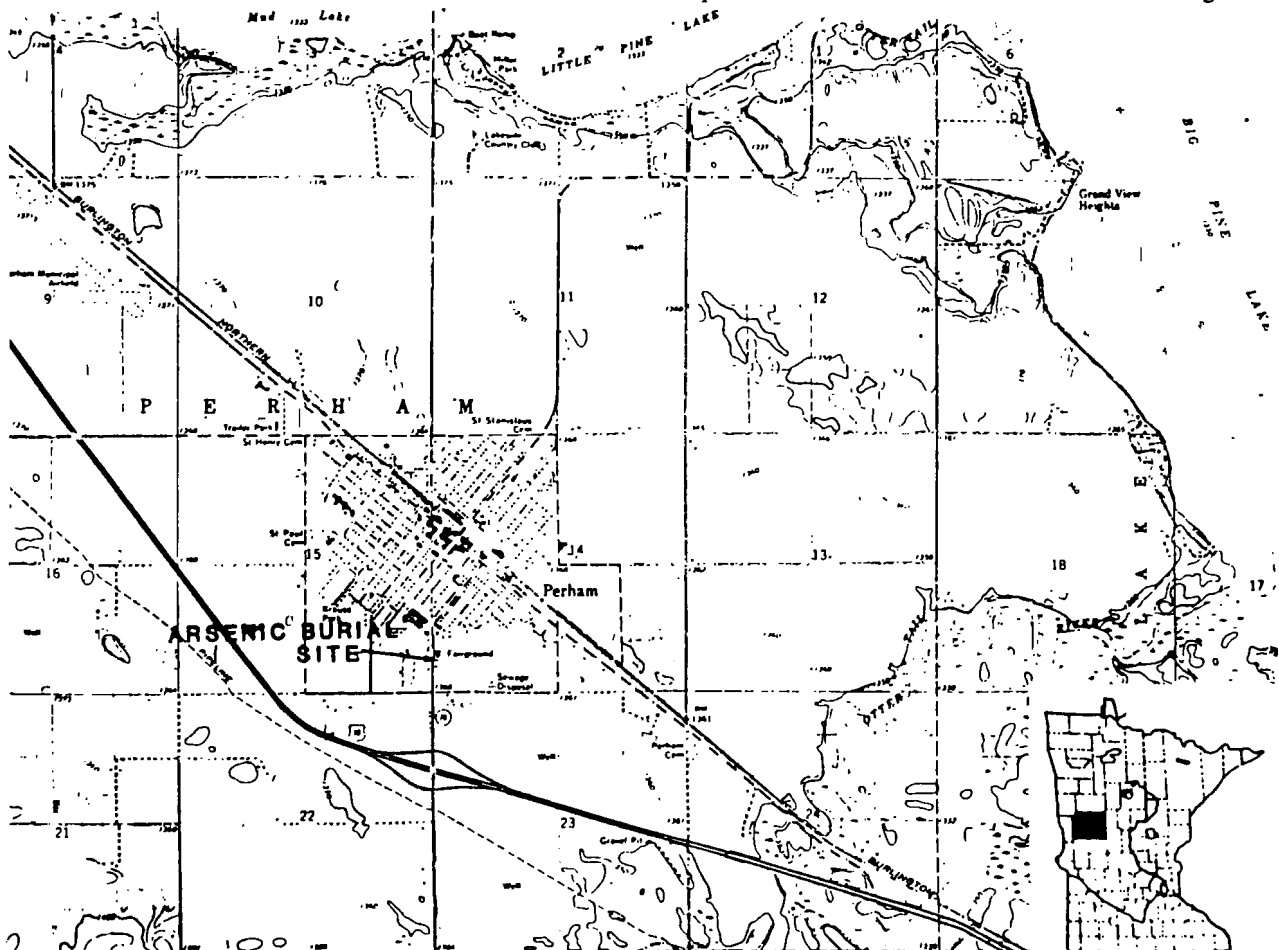
Figure 1
Regional Location Map
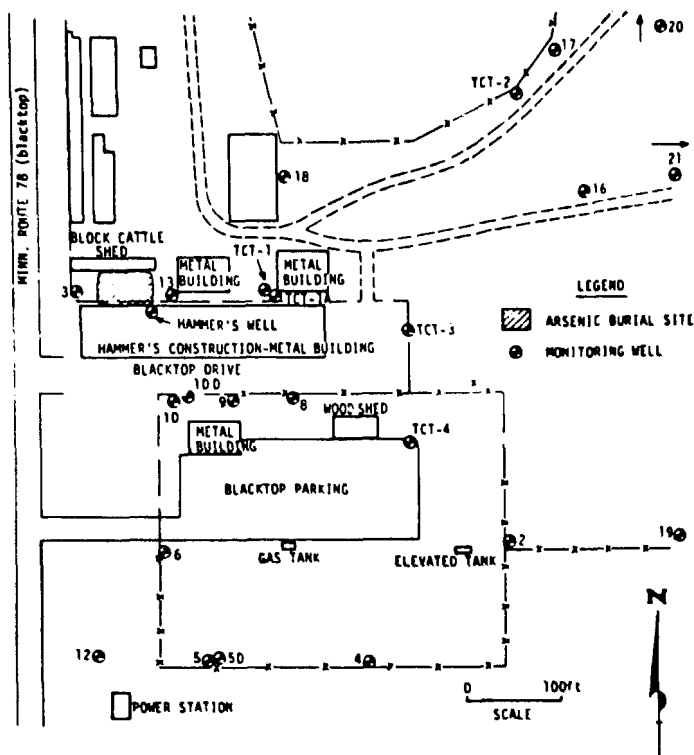
Figure 2
Site Vicinity and Monitoring Well Location Map
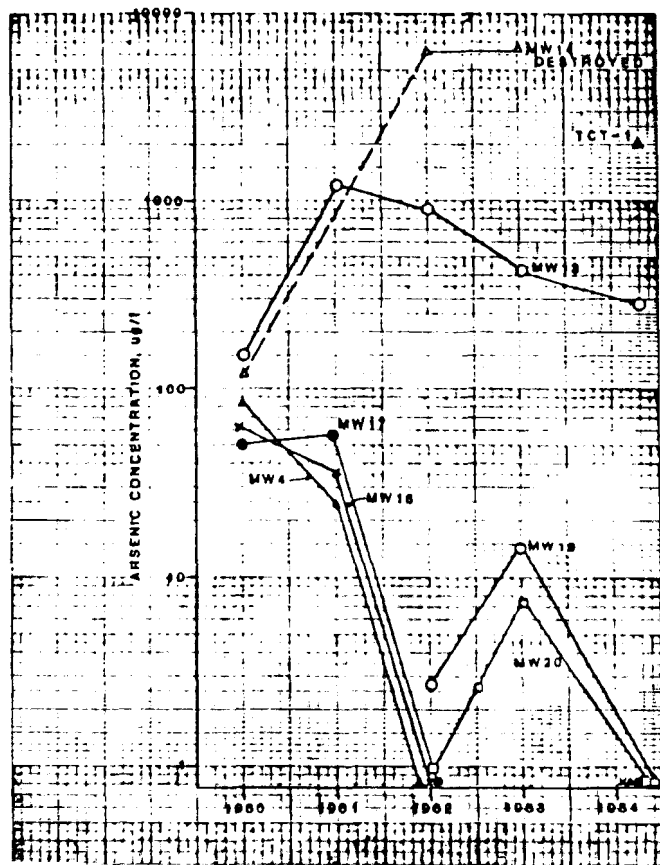
Figure 3
Chronological Changes of Arsenic in Groundwater from 1980 to 1984

12,600 mg/kg. A zone of contaminated soil with arsenic levels exceeding 70 mg/kg extends downward to about 14 ft, and concentrations up to 30 mg/kg have been measured in soil core samples taken at a depth of 19 ft. Background levels of arsenic in soil around the fairgrounds are less than 1.0 mg/kg. Soil with arsenic concentrations at or above 500 mg/kg is considered hazardous according to Minnesota regulations.

Groundwater contamination from the buried waste has been monitored since 1972, when 11 people were poisoned from a well constructed near the edge of the buried waste (Hammer's well); arsenic concentrations up to 21 mg/l were measured in water from that well. In 1980, water from wells down-gradient from the buried waste (about 350 ft from the trench) showed arsenic concentrations up to 0.12 mg/l. Data gathered in 1980 indicated groundwater concentrations which exceeded the drinking water standard (Fig. 3). Background concentrations in area groundwater are less than 0.001 mg/l.

The burial site was covered with a plastic liner and a clay cap in 1982. More recent samples (taken in 1983 and 1984) show lesser concentrations in several of the wells down-gradient from the trench. In fact, most of the recent samples are less than the drinking water standard. The chronological changes in arsenic concentrations in the wells surrounding the burial site are shown in Figure 3.
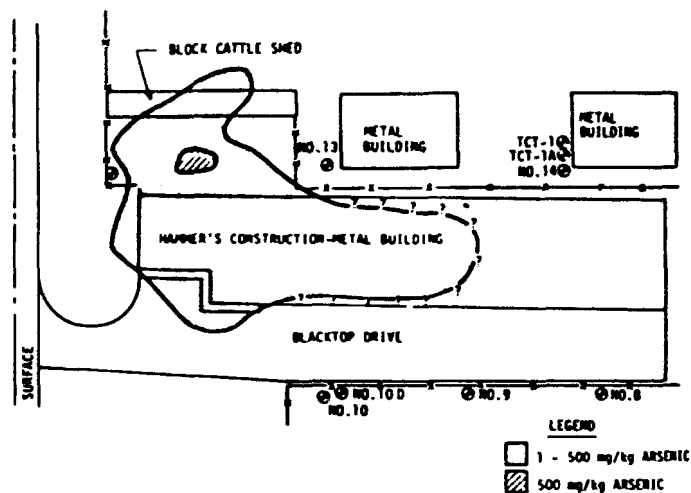
Figure 4
Estimated Boundaries of Contaminated Soil Excavation
(Arsenic > 500 mg/kg), Assuming Vertical Walls.

The Minnesota Pollution Control Agency (MPCA) hired Twin City Testing (prime contractor) and PEDCo Environmental, Inc. (PEI, subcontractor) to conduct a remedial investigation/feasibility study for the Perham site. Twin City Testing conducted the remedial investigation and issued a report (June 30, 1984) describing the site; PEI performed the feasibility study. In a separate report, PEI made a qualitative assessment of technologies for remedial action at the Perham site. Each technology was described with respect to environmental effectiveness, feasibility/applicability and relative costs.

As a result of that evaluation, four alternatives were chosen and approved by MPCA for more detailed evaluation:

1. Increased groundwater monitoring
2. Groundwater pumping and treatment
3a. Excavation and landfilling of all arsenic-contaminated soil
3b. Excavation and landfilling of hazardous soil only (i.e., that soil with arsenic levels ≥ 500 mg/kg)
4a. Excavation and landfarming of all contaminated soil
4b. Excavation and landfarming of nonhazardous soil only and landfilling of hazardous soil

PEI evaluated these alternatives in detail, recommended one alternative and developed a conceptual design for the recommended alternative.

Table 1
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Alternative 1 Increased groundwater monitoring	Alternative 2 Groundwater pumping and treatment
1. Special engineering considerations	None. Install 5 additional monitoring wells	Considerable bench tests of treatment technologies would be necessary before design and implementation could be done. Pumping tests would also be necessary before designing the well system.
2. Environmental impacts		
Air	None	Slight. Some ventilation of arsine is possible; however, amounts would be very small.
Surface water	None	Slight to moderate. Treated or untreated groundwater containing arsenic at or below the drinking water standard would be released to surface waters
Groundwater	Existing contamination would remain and could increase	Minimal. This alternative reduces the arsenic in groundwater below the site
Soil	Some contamination of soil would remain and could increase	Some contamination of soil would remain and could increase.
Overall impact on community	Low. Impact is minimal as long as contaminated soil and groundwater remain in place and further migration does not occur	Low. Arsenic wastes remain buried. Collected groundwater is discharged at or below the standard.
3. Operation, maintenance, and monitoring	Quarterly monitoring of 10 wells (sampling and analysis for arsenic)	Considerable attention (labor) must be devoted to proper operation and maintenance of a pumping and treatment facility.
4. Time required for implementation	Short, less than 2 weeks	Short to moderate for a package treatment plant (less than 2 months)
5. Offsite disposal needs and transportation plans	None	Considerable volumes of sludge from effectively softening the groundwater would be be generated. At 1% solids, up to 9600 gal of sludge would be generated; at 12% solids, about 3200 gallons would be generated. The sludge will contain arsenic, but it is not known whether it would be hazardous. If it is hazardous, disposal at Peoria Land Disposal is recommended. If it is not hazardous, it might be land-applied locally with sewage sludge.
6. Legal constraints	None	Surface discharge would require a permit and compliance with the Clean Water Act (40 CFR 401). If sludges are hazardous, the treatment facility would become a generator. Disposal would have to be at a RCRA-permitted site. It must not remain on site for more than 90 days to avoid the need for obtaining a RCRA permit as a treatment, storage, disposal facility.
7. Safety requirements	None, other than normal precautions taken during well installation and when sampling water containing arsenic	Moderate. Only normal safety procedures for handling the treatment chemicals
8. Ease with which it can be phased into individual operable units	Easily divides into quarterly sampling, analysis, and reporting	Can be somewhat divided into units. Pumped groundwater could be stored before being treated and before being discharged to surface water or groundwater after treatment.
9. Implementability and reliability	Immediately and easily implemented. Moderately reliable. It is unlikely that a slug of highly contaminated groundwater would pass beyond the 10 wells without being detected.	Some bench testing would be required before full-scale design and implementation. Reliability of precipitation/coagulation processes in removing low-level arsenic concentrations is not well demonstrated. Failure to achieve necessary arsenic removal could result in violation of permit conditions and wasted expenditures
10. Total costs	15,000	361,000

Table 2
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Alternative 3a
	Excavation and landfilling of all contaminated soil
1. Special engineering considerations	None. Excavation of 1800 yd³ about 20 ft deep is routine.
2. Environmental impacts	
Air	Possible release of arsenic as fugitive dust during excavation and handling, also small amounts of arsine gas. Dust suppression techniques such as light sprays of water on the working face would minimize particulate emissions. Personal protective equipment would protect workers from arsine exposure.
Surface water	Possible contamination of surface water from runoff from rainfall during the excavation process. Can be prevented by excavating during dry weather.
Groundwater	Existing groundwater contamination would remain; however, the source of possible additional arsenic from the waste would be removed, resulting in eventual (long-term) reduction of arsenic in the groundwater.
Soil	Contaminated soil would be removed and replaced with clean fill.
Overall impact to community	Possible negative impacts are air and surface water contamination. Positive impacts include removal of a hazardous waste and preclusion of additional groundwater contamination.
3. Operation, maintenance, and monitoring	Operation is straightforward and simple. The only maintenance required after the backfill is in place is revegetation of the excavated area. Air monitoring should be conducted during excavation. Continued groundwater monitoring is advisable for some time after excavation.
4. Time required for implementation	Short. Excavation can be completed within 2 weeks. Transport and disposal would take another week. Peoria Land Disposal requires 1 month lead time to approve waste for their landfill.
5. Offsite disposal needs and transportation plans	The closest approved landfill is about 300 miles away; others are 400 or more miles away. Transport of the 1800 yd³ of soil would be by the selected disposal facility or by a local approved transporter.
6. Legal constraints	Waste would have to be manifested and sent to an approved landfill to comply with RCRA.
7. Safety requirements	Personal protective equipment may be necessary for those involved in the excavation.
8. Ease with which it can be phased into individual operable units	Operation can be divided into excavation, packaging in drums or in bulk trucks, transport, and disposal. Excavation and packaging must be done together. Transport and disposal can be done as units separate from excavation and packaging.
9. Implementability and reliability	The excavation and disposal are easily implemented and are very reliable. Failures could include leaving some arsenic-contaminated soil in the ground or spilling material as it is packaged or transported, all of which can be minimized or eliminated.
10. Total costs	398,000

Table 3
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Alternative 3b
	Excavation and disposal of hazardous soil only
1. Special engineering considerations	Minimal. Excavation of 200 yd³ about 6 feet deep is routine. Will require many soil core samples and analysis to define perimeter of area requiring excavation (arsenic >500 ppm).
2. Environmental impacts	
Air	Possible release of arsenic in fugitive dust and small amounts of arsine gas during excavation. Dust control measures such as light sprays of water on working face will minimize dust. Personal protective equipment will reduce possible exposure to arsine.
Surface water	Possible contamination from runoff during excavation. This can be eliminated by excavating during dry weather.
Groundwater	Existing groundwater contamination would remain. Because the most concentrated source of arsenic (the highly contaminated soil) would be removed, little further leaching into groundwater should be minimal. Replacement of the plastic liner and clay cap will reduce the likelihood of further leaching from less contaminated soil remaining in place.

Table 3 (continued)
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Alternative 3b Excavation and disposal of hazardous soil only
Soil	Highly contaminated soil would be removed and disposed of at an approved landfill; lesser contaminated soil would remain in place.
Overall impact to community	Minimal negative impact from possible release of arsenic into the air during excavation. Moderate positive impact due to removal of hazardous waste from area.
3. Operation, maintenance, and monitoring	Minimal. Excavated area will have to be backfilled, regraded, and recapped. Continued groundwater monitoring is advisable for some time.
4. Time required for implementation	Short. Excavation can be completed in 1 week. Transport and disposal would require up to a few days. Peoria Land Disposal requires 1 month lead time to approve waste for their landfill. Initial soil core monitoring to define the area to be excavated would also require lead time of about 2 weeks.
5. Offsite disposal needs and transportation plans	About 200 cubic yards of material would require disposal at an approved landfill. Transportation would be by the selected disposal facility or by a local approved transporter. The nearest disposal facility is about 300 miles from Perham.
6. Legal constraints	Hazardous waste would have to be manifested and sent to an approved landfill to comply with RCRA. The nonhazardous soil remaining at Perham is not regulated.
7. Safety requirements	Personal protective equipment may be necessary for those involved in the excavation.
8. Ease with which it can be phased into individual units	Operation can be divided into soil core sampling and analysis, excavation, transport and disposal, and site closure (backfilling, grading, and recapping). Site closure should immediately follow excavation.
9. Implementability and reliability	The excavation and disposal are easily implemented and are very reliable. Failures could include leaving some hazardous soil inplace that could contribute to further groundwater contamination; spilling hazardous soil as it packaged or transported; and generation of contaminated runoff during excavation. Measures to minimize failures include thorough characterization of the hazardous area's dimensions from soil core sampling and analysis; careful handling practices; and conducting excavation during dry weather.
10. Total costs	$93,000

Table 4
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Excavation and landfarming of all contaminated soil
1. Special engineering considerations	Considerable engineeing is required to complete demonstration plan and program for a RCRA permit and for facility design and operation.
2. Environmental impacts	
Air	Possible release of arsenic as fugitive dust and of small amounts of arsine during excavation and landfarming. Dust emissions can be minimized by water sprays.
Surface water	Possible contamination from runon and runoff from contaminated soil could be minimized by excavating during dry weather and by controls at landfarm site, such as site slope, berms, and runoff collection basins.
Groundwater	Existing contamination of groundwater would remain, but it may decrease over the long term because the source of arsenic would be removed. Possibility for groundwater contamination at the landfarming site is minimal due to immobilization in soil and dilution of waste over a larger area.
Soil	Existing contaminated soil would be removed and spread over a larger area. This would contaminate a larger amount of soil, but the concentration would be lower. Contamination of additional soil would be essentially permanent.
Overall impact to community	Negative impact includes possible air emissions during excavation and landfarming and contamination of the landfarming plot with arsenic. Positive impacts include removal of a hazardous waste at Perham and conversion of the highly concentrated arsenic into a nonhazardous concentration through landfarming.

Table 4 (continued)
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Excavation and landfarming of all contaminated soil
3. Operation, mainte- nance, and monitoring	Considerable. Operation of demonstration program and full-scale landfarming require engineering design, land preparation, water control measures, waste applications, and vegetation of plot. Maintenance of vegetative cover and water control measures are required. Monitoring needs include sampling and analysis of air, soil, soil pore-liquid, runoff, and groundwater.
4. Time required for implementation	Considerable, about a year or more. The demonstration plan and program take from several months to a year. Full-scale landfarming would take less than a month, but monitoring for a year afterwards would probably be required.
5. Offsite disposal needs and transpor-tation plans	Transport should be by a local approved hazardous waste transporter. No offsite disposal is anticipated unless large amounts of contaminated runoff are accumulated that cannot be reapplied to the site. This would have to be treated.
6. Legal constraints	The landfarming site would have to be permitted under RCRA. This requires substan-tial planning, engineering, and monitoring and will take some time to obtain, but it can be done.
7. Safety requirements	Personal protective equipment (Level C) is recommended. Air monitoring should alert working personnel of the need for additional or for less protection.
8. Ease with which it can be phased into indi-vidual operable units	Can be divided into excavation of a small amount of soil for the demonstration program, followed by complete excavation, transport, landspreading, revegetation, monitoring, and closure.
9. Implementability and reliability	If the demonstration program is successful in proving that the arsenic is immobilized, then the application for a permit should be approved and the full-scale operation should be reliable.
10. Total costs	$128,000

SAMPLES FROM TRENCH
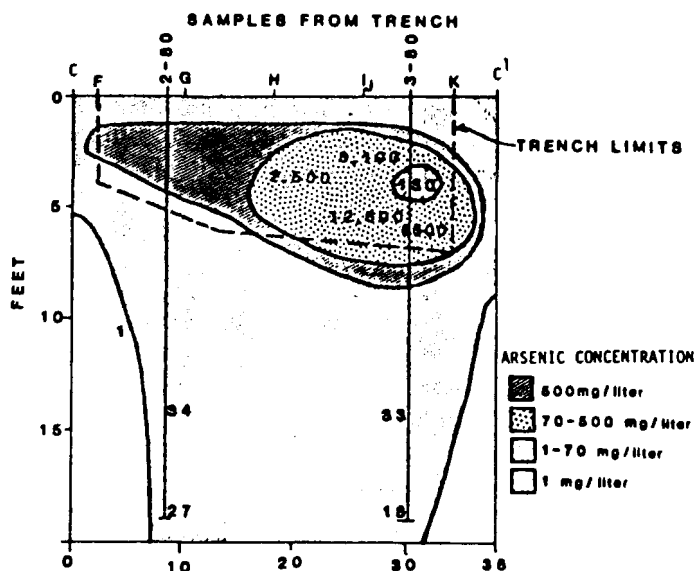
Figure 5
Vertical Soil Profile C-C¹ with Arsenic Concentration Contours

RESULTS

The evaluation of each of these alternatives is shown in Tables 1 to 5 while the costs are summarized in Table 6. These costs are ± 20%; no contingencies have been included.

Option 1, increased groundwater monitoring, would cost about $15,000 for the first year, assuming installation of four additional monitoring wells, and about $4000 per year thereafter for quarterly monitoring. Option 2, groundwater pumping and treatment, is the most expensive alternative costing in excess of $360,000. Option 3a,

excavation and landfilling of all the contaminated soil, would cost about $394,000 based on disposal at a landfill in Peoria, Illinois. Other landfills charged considerably more, so this price represents a minimum; the cost could range up to $500,000 depending on the site selected. Option 3b, excavation, landfilling and recapping at Perham, would cost about $90,000. This is the second most economical alternative. Option 4a, excavation and landfarming of all the contaminated soil, would cost about $128,000. Option 4b, excavation of all the soil, disposal of the hazardous soil and land-farming of the nonhazardous soil, costs about the same, approx-imately $124,000.

The information summarized in Tables 1 through 5 is rated in a semiquantitative manner in Table 7 by assigning numbers to each factor discussed previously. As explained in the table, nearly all factors are assigned a number of 1, 2 or 3, and the factors are summed to allow a comparison of all the alternatives. Environmen-tal factors accounted for 5 of the 14 factors rated because air, sur-face water and other media are each considered separately. Costs, the last factor, are assigned ratings of 1, 2, 3, 4 or 5 (rather than 1, 2 or 3) because costs are such an important consideration and because they vary over a large range.

A low score in the summed rating is best; i.e., it indicates that an alternative is generally more feasible, has less adverse environ-mental impact and is more cost-effective than an alternative with a higher score. The lowest-scoring alternatives are (in order) in-creased groundwater monitoring, landfilling all of the con-taminated soil and landfilling only the hazardous soil. Because landfilling all of the soil would cost about six times more than land-filling only part of the soil, the option of landfilling all of the soil was not considered further.

RECOMMENDATIONS

Two alternatives were considered in the final recommendations. The first is to leave the arsenic in place and increase the ground-water monitoring. This alternative is certainly the least expensive, unless it is continued over a period of 10 or 12 years. In this case, it

Table 5
Evaluation of Remedial Alternatives at Perham

Evaluation factors	Alternative 4b Excavation, disposal, and landfarming
1. Special engineering considerations	Minimal. Some design of landfarming operation is necessary.
2. Environmental impacts	
Air	Possible release of arsenic in fugitive dust and small amounts of arsenic gas during excavation. Dust control measures such as light sprays of water on working face will minimize dust. Personal protective equipment will reduce possible exposure to arsine.
Surface water	Possible contamination from runoff during excavation. This can be eliminated by excavating during dry weather.
Groundwater	Existing groundwater contamination would remain, but would eventually (long-term) diminish because source of arsenic would be removed.
Soil	Contaminated soil would be removed. Hazardous soil would be disposed of at an approved landfill; nonhazardous soil would be landfarmed, resulting in small increases of arsenic in the landfarm plot.
Overall impact to community	Minimal negative impact from possible release of arsenic into the air during excavation. Moderate positive impact due to removal of hazardous waste from area.
3. Operation, maintenance, and monitoring	Operation would require excavation, soil sampling, and analysis to divide soil into hazardous and nonhazardous fractions, transport to both a disposal facility and a landfarm plot, waste application, and vegetation. Maintenance and monitoring are not mandatory; however, some soil and soil-pore liquid monitoring is advisable.
4. Time required for implementation	Several weeks to months
5. Offsite disposal needs and transportation plans	Transport to an approved disposal facility could be by the facility or by a local approved transporter of hazardous wastes. The nearest suitable landfill is 300 miles away. Transport of nonhazardous soil could be by a local transporter.
6. Legal constraints	Hazardous soil has to be accompanied by a manifest and taken to a RCRA-permitted facility by a permitted transporter.
7. Safety requirements	Personal protective equipment (Level C) is advised for excavation operations.
8. Ease with which it can be phased into individual operable units	Units are excavation of hazardous soil, transport and disposal, excavation of nonhazardous soil, transport, and landfarming. Optional activities include landfarm site revegetation, closure, and monitoring.
9. Implementability and reliability	The only difficulty will be in adequately differentiating between hazardous and nonhazardous soil.
10. Total costs	$124,000

Table 6
Cost Summary

Option	Approximate cost ($)
1. Increased groundwater monitoring (monitoring = $4,000/yr)	15,000
2. Groundwater pumping and treatment	361,000
3a. Excavate and landfill all contaminated soil	398,000
3b. Excavate and landfill hazardous soil only	93,000
4a. Excavate and landfarm all contaminated soil	128,000
4b. Excavate all contaminated soil: dispose of hazardous soil, landfarm nonhazardous soil	124,000

is comparable to excavation and landfill disposal of only the hazardous soil (which represents a one-time cost). At the present time, the arsenic does not pose a risk because the clay cap prevents exposure by air or surface water, and the contaminated groundwater is not currently being used. Increased monitoring would make it unlikely that a slug of contaminated groundwater could pass out of the area without being detected in time to implement proper remedial actions.

The major disadvantage to this alternative, however, is that it does not remove the source of contamination or treat the contaminated groundwater. The immediate area of the trench could never be used in any way that would disturb the plastic liner and clay cap, and the contaminated groundwater could not be used. The community would still contain a hazardous waste site. The increasing groundwater monitoring program without removal of waste or groundwater would be perceived as a "do nothing" alternative, which would be socially and politically unacceptable. The option of leaving the waste in place and increasing the groundwater monitoring, although technically acceptable because of minimal risk of exposure, is not socially acceptable and is not recommended.

The recommended remedial alternative at Perham is to conduct extensive soil core sampling and analyses to define the boundaries of the hazardous soil (that soil with an arsenic concentration of 500 mg/kg or more), and then to excavate the hazardous soil and transport it to an approved landfill disposal facility. The lesser-contaminated soil (less than 500 mg/kg arsenic) would remain in place. The excavated area would be backfilled, and the plastic liner and clay cap would be replaced. It is further recommended that the ongoing groundwater monitoring program be continued until the levels of arsenic in all the wells remain below the drinking water standard. This alternative is the second most cost-effective measure. It removes the source of most of the contamination, and it minimizes transport and disposal costs by removing only that

Figure 6
Vertical Soil Profile D-D¹ with Arsenic Concentration Contours

portion of the soil that is most heavily contaminated. Backfilling the excavated area and replacing the plastic liner and clay cap would minimize further leaching of the arsenic remaining in place. Because the groundwater would not be treated, however, it must be restricted from use. The community would most likely be supportive of this alternative.

Required Mapping

The most difficult part of this alternative is the accurate mapping of the area that needs to be excavated. This effort will require the analysis of about 100 soil core samples for arsenic. It has been estimated (from earlier core sampling and analysis) that the area with arsenic concentrations exceeding 500 mg/kg is about 35 ft × 25 ft × 6 ft, with depths ranging from 2 to 8 ft, for a volume of about 200 yd³. An overburden of about 130 yd³ could be stockpiled and used for backfill. The contaminated area extends to within about 5 ft of the Hammer's building. Although this will not interfere with operations, it is recommended that the cattle shed opposite the Hammer's building be removed to provide enough room for a backhoe to maneuver. Because more than 50 soil core samples have already been taken in the area of the trench, the approximate area of greatest concentration is known. The estimated limits of contaminated soil excavation, assuming vertical walls, are shown in Figure 4. The soil core monitoring should be conducted at or near the boundary shown in the figure. Vertical profile locations and concentrations based on previous sampling are shown in Figures 5 and 6. According to these data, the arsenic concentrations in excess of 500 mg/kg extend to about 7 ft deep. The proposed 25 sampling locations are shown in Figure 7. If each location is sampled at 4, 6, 8 and 10 ft, 100 samples will be taken.

After the samples are taken and analyzed, horizontal and vertical profiles should be drawn to map out the hazardous soil area. Samples should be sent to landfills for approval (up to 1 month lead time is required).

After the area for excavation is mapped, the State should solicit bids for the excavation, for transport and disposal and for environmental monitoring. Bids should include provisions for workers to be equipped with personal protective equipment during the excavation efforts.

Before excavation is begun, the area to be excavated should be delineated and the remaining clean ground should be covered in

Table 7
Ranking of Evaluation Factors for Remedial Alternative for Perham

Evaluation Factors	1	2	3a	3b	4a	4b
1. Special engineering considerations 1—None to few 2—Moderate 3—Major	1	3	1	1	3	2
2. Adverse environmental impacts Air— 1—Minor 2—Moderate 3—Major	1	1	2	2	3	2
Surface water— 1—Minor 2—Moderate 3—Major	1	2	2	2	2	2
Groundwater— 1—Minor 2—Moderate 3—Major	2	1	2	2	2	2
Soil— 1—Minor 2—Moderate 3—Major	2	2	1	2	3	2
Overall impact to community— 1—Minor 2—Moderate 3—Major	1	2	1	2	3	2
3 Operation, maintenance, and monitoring 1—None to little 2—Moderate 3—Major	2	3	2	2	3	2
4 Time required for implementation 1—Short, less than 1 month 2—Moderate, 1 to 2 months 3—Long, more than 2 months	3	2	1	2	3	2
5. Off-site disposal needs and transportation plans 1—None 2—Moderate 3—Major	1	2	3	3	3	3
6 Legal constraints 1—None to few 2—Moderate 3—Major	1	2	1	1	3	2
7. Safety requirements 1—None to few 2—Moderate 3—Major	1	1	2	2	3	2
8. Ease with which it can be phased into individual operable units 1—Easy 2—Moderate 3—Difficult	1	2	2	2	2	2
9 Implementability & reliability 1—Easy 2—Moderate 3—Difficult	1	3	1	1	3	2
Subtotal	18	26	21	24	36	27
10. Total costs for 1st year 1—Less than $100,000 2—$100,000 to $200,000 3—$200,000 to $300,000 4—$300,000 to $400,000 5—Greater than $400,000	1	4	4	1	2	2
Total	19	30	25	25	38	29

1. Groundwater Monitoring
2. Groundwater Pumping and Treatment
3a. Landfill all
3b. Landfill part
4a. Landfarm all
4b. Landfarm part

Figure 7
Proposed Soil Core Sampling Locations

plastic to prevent its contamination. The bucket of the backhoe also should be lined with plastic to facilitate decontamination at the end of the work effort.

Safety Procedures

Persons hired to work in the hazardous area should be adequately trained in proper use of protective equipment and safety procedures. Medical examinations are recommended prior to site work to ensure workers' fitness for this kind of work. Personal samplers should be used on-site. According to the OSHA Inorganic Arsenic Standard, *CFR 29*, Part 1910.1018, determinations of airborne exposure levels shall be made from air samples representative of each employee's exposure to inorganic arsenic over an 8 hr period.

As an initial precaution (pending results of air monitoring), all employees exposed to inorganic arsenic must be supplied with and required to wear a NIOSH-approved respirator and protective suits, gloves and boots. Level C protective equipment, modified to close gaps at the neck or around the face, is recommended. The employer must provide workers with showers and clean changing and eating facilities. The employer also must post the area where inorganic arsenic is being handled.

If the results of the initial air monitoring indicate exposure levels in excess of 5.0 $\mu g/m^3$, personal protective equipment (respirators

and clothing) and showers are required. Also required are continued medical surveillance, recordkeeping and any other items included in the site-specific health and safety plan. If the air levels are less than < 5.0 $\mu g/m^3$, these precautions are not required, but careful handling of the arsenic is still necessary.

At the beginning of the excavation, the clay caps and plastic liner should be removed and retained. Excavation will proceed daily until the project's completion. At the end of each day, any contaminated disposal materials (respirator cartridges, clothing, etc.) should be placed in the bucket of the backhoe and removed with the plastic liner to the disposal trucks in which the hazardous soil has been placed. Waste leaving the site by truck must be manifested, with the State listed as generator.

When excavation has been completed, clean fill should be placed in the excavated area. After the area is leveled, the plastic liner and clay cap should be replaced. Thereafter, the clay cap should be inspected periodically (when the groundwater monitoring wells are sampled) to ensure its integrity, and repairs should be made as needed.
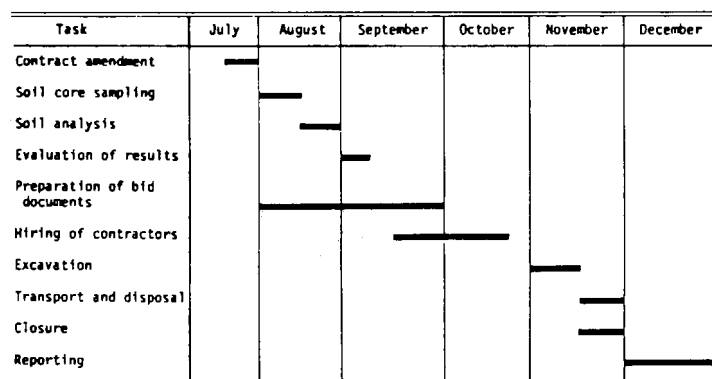
Figure 8
Implementation Schedule of Recommended Alternative

CONCLUSIONS

This recommended alternative could be completed within 6 months. Because some landfills require a lead time of up to a month to approve a waste, a sample should be sent to landfills under consideration as soon as possible. During this time, preparation of bid documents and selection of contractors for excavation, hauling and disposal will be started. The approximate schedule for the required tasks is shown in Figure 8. The schedule does not include continued groundwater monitoring which may entail several years of periodic sampling and analysis.

ENFORCEMENT REMEDIAL CLEANUP AT THE PETRO PROCESSORS SITE; BATON ROUGE, LOUISIANA

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INTRODUCTION

The Comprehensive Response, Compensation and Liability Act (CERCLA) provided the USEPA with the authority to effect cleanup of hazardous waste sites through two mechanisms. The first is through initiation of federally financed response actions funded from the $1.6 billion trust fund established under the statute. The second, less publicized, mechanism is by activities in the USEPA's Superfund Enforcement Program aimed at compelling private responsible parties to clean up sites thereby supplementing limited Superfund resources. An example of USEPA's successful application of its enforcement authorities under CERCLA is the Petro Processors site near Baton Rouge, Louisiana.

Site Background

The Petro Processors site is located in Scotlandville, Louisiana, just outside of Baton Rouge. The site covers approximately 62 acres and is comprised of two disposal areas, Scenic Highway and Brooklawn, located approximately 1½ miles apart. Both disposal areas are located on the banks of Bayou Baton Rouge with the Brooklawn area located in the floodplain of the Mississippi River.

The Scenic Highway and Brooklawn disposal areas were both owned by Petro Processors of Louisiana, Inc., and operated from approximately 1964 to 1980. Waste generators from nearby petrochemical and chemical plants contracted with Petro Processors for disposal of their waste products.

The wastes are present in several phases: solid, semi-solid, gelatinous, sludge, liquid and mixed industrial debris (scrap metal, rubber, plastics). The main contaminants of concern are highly toxic volatile organic compounds present in high concentrations.

Both disposal areas exhibit similar hydrogeologic features. The site is generally underlain by clay and silt deposits with extensive seams of sand lenses. A shallow alluvial aquifer is present in a sand strata located at depths of about 30 to 40 ft below mean sea level. Beneath the alluvial aquifer are several layers of clay and a major aquifer commonly referred to as the "400-foot sands aquifer." This aquifer, which begins at depths of about 100 ft below mean sea level in the vicinity of the site, is an important water source for industrial use and some private drinking wells in the area. Significant levels of contamination have been detected in the alluvial aquifer and in Bayou Baton Rouge. No contamination has yet been detected in the 400-ft deep sands aquifer in the vicinity of the Petro Processors site.

The Scenic Highway disposal area covers approximately 7 acres and is located between a major highway, U. S. Route 61 (Scenic Highway) and Bayou Baton Rouge. The site is a former borrow pit from construction of Scenic Highway. Beginning in 1964, wastes were disposed of in the borrow pit. The Scenic Highway disposal area was filled and closed around 1974. Most of the liquid wastes were solidified, fill dirt was added and plastic sheeting and a soil cap were installed. The cap is now in disrepair.

A major concern at this site is the potential and actual exposure and migration of toxic materials by erosion from Bayou Baton Rouge as well as subsurface seepage. It has been estimated that approximately 320,000 tons of waste material were disposed of at the Scenic Highway disposal area.

Brooklawn is the larger disposal area covering approximately 55 acres. It was opened in the late 1960s and was in full operation by 1970. It did not completely cease operation until a suit was filed by the USEPA in July 1980. Approximately 19,000,000 gal of liquid wastes and an additional 900,000 tons of non-liquid wastes were disposed of at Brooklawn.

The Brooklawn disposal area includes two open waste disposal pits, a leveed cypress pond and several disposal pits which have been filled and covered with soil. The Mississippi River periodically inundates much of the area. As recently as June 1983, the cypress pond was flooded and the water came within 4 in. of flowing over the dike into the lower pit. A large disposal pit (now filled) was constructed over an old channel of the bayou. This channel is a suspected conduit for subsurface migration of wastes. Subsurface contamination has been found outside of the disposal areas.

Enforcement History

The USEPA first became involved with the Petro Processors site in May 1980 when inspections conducted by USEPA and the State of Louisiana revealed that open waste pits were overfilled and in danger of overflowing. In addition, evidence showed that wastes had been directly discharged from the waste pits into Bayou Baton Rouge.

The USEPA and Louisiana filed a lawsuit in Federal Court in July 1980 seeking cessation of the discharges and a full investigation and cleanup of the site. The lawsuit named the owner/operator and ten companies who had generated wastes sent to the Petro Processors site as defendants. The lawsuit was filed under RCRA, the Clean Water Act and the Refuse Act and was later amended to include counts under CERCLA.

Subsequent to filing the lawsuit, the USEPA continued to investigate the site to better define the potential threats to public health and the environment. Those investigations revealed both organic phase and aqueous phase contamination in the alluvial

aquifer beneath and migrating from the site. In addition, contamination was found in the sediments of Bayou Baton Rouge and in other off-site areas. Site geologic conditions gave rise to serious concern over the potential for contamination of the deeper (400-ft) sands aquifer. The USEPA was similarly concerned about the continuing seepage of wastes from pits adjourning Bayou Baton Rouge and the possibility of massive releases in the event of failure of deteriorating dikes around the open waste disposal pits.

In response to the concerns expressed by the USEPA and the State regarding the conditions of the open waste pits, the industry defendants entered into a stipulation, filed with the Court in December 1981, whereby the defendants provided $218,000 to the State in order to implement certain interim remedial measures. Those measures, which were carried out by the State's contractor in April 1982, included reinforcing dikes, diverting surface water, improving freeboard and providing better site security. When heavy rains again caused liquid levels in the waste pits to rise dangerously high in February 1983, industry defendants conducted an emergency removal of aqueous liquids for disposal off-site in an injection well, all under the supervision of the USEPA and State on-scene coordinators.

After more than three years of technical discussions and negotiations failed to produce an agreement for remedial cleanup, trial in the lawsuit was convened on Dec. 5, 1983; however, with extensive participation by the Court, a settlement agreement was reached with the industry defendants on that same day. The settlement agreement was embodied in a Consent Decree which was lodged with the Court Dec. 15, 1983.

Under terms of the Consent Decree, the 10 industry defendants agreed conceptually to a cleanup program for the entire Brooklawn and Scenic Highway disposal areas. Specifically, the Consent Decree requires the industry defendants to: (1) perform detailed remedial planning activities; (2) design, construct and implement the agreed upon conceptual closure plan which includes a state-of-the-art landfill and groundwater recovery systems; and (3) maintain perpetual operation, maintenance and monitoring of the site.

If, after implementation of the closure plan, the monitoring program detects a release or threat of release of contaminants from the site, the industry defendants are required by the Consent Decree to submit a supplemental remedial action plan to prevent or mitigate any such release and to implement any additional remedial action. Further, notwithstanding results of the monitoring program, the government parties reserved their rights to reopen the case and seek additional remedial action which may be necessary to prevent or mitigate contamination in the deep sands aquifer in the event that there may be changes in either land use near the site, aquifer use, groundwater flow direction or velocity, or an endangerment is presented by site conditions.

In addition to implementation of the closure plan, which is estimated to cost approximately $50 million and will take several years to implement, the industry defendants reimbursed the Hazardous Substance Response Trust Fund $600,000 to cover the USEPA's investigation and enforcement costs. These funds will be used for future site cleanups.

CONCEPTUAL CLOSURE PLAN

The conceptual closure plan attached to the Consent Decree provides the technical framework, details and design criteria for the agreed upon remedial action as well as the operation, maintenance and monitoring programs. Prior to design and implementation of the closure plan, the industry defendants will also perform several remedial planning activities.

Included among the remedial planning activities are: a site characterization study which will be essentially a remedial investigation and feasibility study to determine the nature and extent of groundwater contamination and to evaluate remedial alternatives necessary to prevent or mitigate contamination of the deep sand aquifer; a health and safety plan; a quality assurance/quality control program; a waste solidification testing program; a liner compatibility testing program; and a study evaluating the suitability of proposed landfill sites.

Waste Removal

The conceptual closure plan requires solid and semi-solid waste materials from both the Scenic Highway and Brooklawn disposal areas as well as contaminated sediments and soils from the cypress pond, Bayou Baton Rouge and adjacent property to be excavated and mixed with appropriate solidification agents prior to disposal in a state-of-the-art landfill. The appropriate solidification agents will be determined through the testing program in the remedial planning activities.

Wastes to be removed from the Brooklawn and Scenic Highway disposal areas will include all visible wastes plus 1 ft of soil or sediment from all faces of the excavation. On a portion of adjacent property which had been contaminated from a spill several years earlier, three feet of soil and sediments will be removed even if there are no visible wastes present. All excavated materials will be handled and treated as hazardous. The excavated areas of the site will be partially backfilled and graded to provide drainage of surface runoff. A protective cap system will be constructed and include three feet of low permeability clay (10^{-7} cm/sec or less), a vegetative layer and will be seeded or hydromulched to provide a grass cover.

Geotechnical Tests

Geotechnical testing will be performed in the Brooklawn bluff areas to determine the feasibility of allowing in situ containment of wastes buried in that area. Soil borings will be taken to determine the existence of a continuous layer of low permeability clay (aquitard) of sufficient thickness to serve as a barrier to vertical waste migration. If an adequate clay layer does exist, then the bluff disposal area will be encircled with cutoff walls keyed into the clay with a multi-layer cap system installed over the disposal area. Any liquid wastes within the containment area will be either solidified and disposed, incinerated on-site, or treated, stored or disposed of as hazardous waste in a RCRA permitted off-site facility. If an adequate clay layer does not exist, then the wastes will be excavated, solidified and disposed of in the state-of-the-art landfill.

Groundwater Treatment

Two groundwater recovery pumping systems will be installed and operated to extract and treat subsurface liquid contaminants. The first groundwater recovery pumping system will be designed to remove and treat any organic liquid phases present beneath the site. The organic phase recovery wells will be installed and operated in those areas where organic phase liquids have been detected during investigation activities. Organic phase recovery wells will be pumped until the organic phase liquids are no longer present as determined by monitoring of effluent from the pump discharge.

The second groundwater recovery system will be designed to extract and treat aqueous phase contaminants (contaminants dissolved in water) from the groundwater. This system will be installed where appropriate at both disposal areas to recover and treat aqueous phase contaminants from the shallow alluvial aquifer located in sand lenses at about elevation minus 40 mean sea level. The aqueous phase groundwater recovery system will be pumped as necessary (for a minimum of three months) to prevent contamination of the deeper uncontaminated deep sands aquifer. If contamination cannot be prevented, additional remedies may be sought to prevent any endangerment to potential groundwater users.

Contaminated water from the waste disposal pits, cypress pond and the well recovery system will be treated and discharged in accordance with an NPDES permit. Organic phase contamination recovered from well recovery systems will be stabilized, solidified and disposed in the landfill, incinerated on-site, or treated, stored or disposed of as a hazardous waste at an off-site RCRA permitted facility.

State-of-the-Art Landfill

A state-of-the-art landfill will be constructed on-site or on adjacent property. The landfill will meet the substantive technical requirements of RCRA, although a permit will not be required.

The landfill will incorporate a liner syster composed of 3 ft of clay with a permeability less than 10^{-7} cm/sec, a flexible membrane (synthetic) liner and a leachate collection system. The material and thickness of the flexible membrane liner will be determined through compatibility testing conducted as part of the remedial planning activities. The bottom of the liner system will be above the 100-year flood elevation and the historic high ground water elevation.

A multi-layer cap system which minimizes the infiltration of liquids into the landfill in the long-term will cover the top and sides of the landfill. The cap system will include a barrier layer composed of both a layer of clay with a permeability of less than 10^{-7} cm/sec and a flexible membrane liner, a porous drainage layer (if necessary) and a vegetable layer to prevent erosion. The landfill will be designed and operated to prevent run-on from the peak discharge of at least the 25-year storm and to collect and control runoff from at least the 24-hr, 25-year storm event. Furthermore, the design will employ appropriate design or operational controls necessary to prevent wind dispersal of particulate matter.

The landfill design will include the location and specifications for groundwater monitoring wells capable of detecting any potential releases of contaminants from the landfill into groundwater. If the final landfill design includes a leachate detection system and backup flexible membrane liner in addition to the required leachate collection system, flexible membrane liner and clay liner, then groundwater detection wells may not be required. However, in the event that leachate is discovered in the leachate detection system, a groundwater monitoring system will be installed.

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SUBSURFACE GEOPHYSICAL INVESTIGATION AND SITE MITIGATION

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INTRODUCTION

During 1977, the Illinois Environmental Protection Agency (IEPA) obtained a circuit court order requiring the owner of a sand and gravel quarry located in rural northern Illinois to remove approximately 400 buried drums of paint wastes and sludges. The wastes were allegedly buried at the operating quarry throughout the 60s and early 70s. It had been reported that portions of the quarry were used to dispose of residential and industrial refuse as well.

In 1979, ownership of the 170 acre quarry was transferred to the County Conservation Department through a purchase arrangement with the previous owner. The County's intent in acquiring the sand and gravel pit was to develop the entire area into a wilderness preservation park complete with camping and hiking facilities and a stream fed lake for fishing and boating. The lake would be created by allowing the quarry to fill naturally with fresh water.

The restoration plans and activities would be scheduled over a period of ten years, while the economic value of the quarry could still be realized through continued mining operations. The ongoing sand and gravel activities conveniently assisted preparation of the site for the future park. The restoration proceeded smoothly until August, 1983.

During the development of a steeply banked area, which would someday be the north shore of the proposed lake, excavation equipment unearthed three rusted drum carcasses. At this point, the restoration effort was stopped and County officials were notified.

BACKGROUND

The County's initial response to the findings at the quarry was to collect samples of material clinging to the drum carcasses and have the material analyzed by a state-operated laboratory. The laboratory reported the presence of aromatic hydrocarbons similar to the drummed wastes which had been exhumed by the previous site owner/operator seven years earlier. County personnel scanned the area with a magnatometer and confirmed their initial concerns about the presence of many more buried metal objects than had originally been unearthed. An emergency meeting of the County Commissioners was called by the president of the Conservation District in order to review the findings and map out a strategy to address the situation which was drawing increasing public concern.

The Board of Commissioners unanimously decided to conduct whatever measures were necessary to remove and properly dispose of the waste materials. A list of available remedial contractors was obtained from the IEPA. Within three days of the Board of Commissioners vote to pursue cleanup of the site, a contractors meeting was held with potential remedial action firms.

The outcome of discussions with potential contractors raised several issues which the Commissioners needed to consider prior to initiation of any on-site remedial activities. They were:
- Could cleanup costs be recovered through any state and/or federal programs or would litigation be required?
- Once the cleanup was initiated, how would the county know the extent of waste removed required?
- If materials identified by way of the county's magnatometer survey were excavated, what assurance would there be that other buried wastes were not present in the surrounding vicinity?
- Would there have to be special state and/or federal requirements for conducting the cleanup?
- Once the wastes were removed, where could they be properly disposed?

SITE INVESTIGATION

In mid-August, 1983, the county contracted with Chemical Waste Management, Inc.'s Environmental Remedial Action Division (CWM-ENRAC) for implementation of remedial site investigations. The recommended initial site investigations consisted of the following geophysical procedures:
- Land surveying
- Terrain conductivity survey
- Ground penetrating radar survey
- Test excavations
- Multiple soil borings

Due to the unknown extent of buried materials, a subsurface investigation consisting of the aforementioned tasks was advisable. The objective of these tests was to develop data for a remedial action plan.

In view of the drum removal activities seven years earlier, investigation was to cover 4.6 acres, thus providing geophysical data for the area surrounding the exposed drum carcasses as well as checking other potential burial locations. Before any on-site activity was conducted, the entire area was monitored with a Century Organic Vapor Analyzer (OVA). This survey determined that the initial site investigations could be safely conducted in USEPA Level D protection, provided the activities did not disturb the soil (Fig. 1). Environmental air monitoring was continued throughout all of the site investigation phase.

Land Surveying

The limits of the land area to be investigated were predicated on the two exposed waste locations. The resultant area was a square

with approximate dimensions of 450 ft per side. Once the investigatory zone had been delineated, a surveying crew established a grid pattern and set grid stakes at 100 ft centers over the parcel and at 25 and 50 ft centers over those portions of the grid which physically exhibited the greatest potential of being areas where burial activities could have taken place. The grid pattern and associated coordinate identifiers were keyed to known permanent features in the immediate vicinity for possible future reference.

Terrain Conductivity Survey

The terrain conductivity survey utilized a Geonics Limited Model EM31 conductivity meter. This meter generates a primary magnetic field which induces electrical currents in the subsurface; the resultant secondary magnetic field is measured and evaluated by conductivity measurement. Terrain conductivity is dependent on the porosity, moisture content, concentration of dissolved electrolytes, temperature and phase state of the moisture, amount and composition of colloids of both soil and rock and presence of introduced high or low conductivity material.

The terrain conductivity survey identifies conductivity anomalies without regard to the source of the anomaly. As a result, the source of the observed anomaly cannot be assigned based solely on the geophysical survey, but must be supported by material exposed at the surface; i.e., historical records, subsurface sampling or excavation and direct observation. The magnitude of conductivity values is not significant in a survey intended to identify anomalies. During this survey, conductivity value adjustments were determined to assure that readings on the instrument's display dial were within a given range of the dial for background values. The survey was conducted by measuring conductivity values on a 25 ft spacing over the entire parcel and on a 12.5 ft spacing in the grid area where most of the conductivity anomalies were found at 25 ft spacing. Measurements were made at locations of grid stakes in the grid area, at locations determined by pacing between stakes where the stakes were either 50 or 100 ft apart and in the area of conductivity anomalies. The location accuracy was judged to be within 2 ft where pacing was used.

The Model EM31 conductivity meter has its dipoles fixed 12 ft apart. At each point surveyed, the long axis of the instrument was oriented in an east-west direction and conductivity values were measured using two different equipment configurations, the horizontal and vertical dipole mode. In the horizontal mode, approximately 75% of the observed conductivity is estimated to be due to material in the region from 0 to 10 ft below ground surface. In the vertical mode, approximately 50% of the conductivity observation is estimated to be due to material in the region from 0 to 10 ft below ground surface, the majority of that response coming from below a depth of 5 ft with little near surface influence. The remaining 50% of the observed conductivity is estimated to be due to material in the region 10 to 20 ft deep. In this discussion, the horizontal dipole mode is called the 10 ft mode and the vertical dipole mode is called the 20 ft mode.

Location and conductivity value information were noted on data forms and then recorded on plan view maps of the grid pattern. Contours of approximately equal conductivity values were then drawn. Conductivity values were transferred to a map of the grid, and approximate contours of anomalous conductivity values were drawn. From the conditions delineated through the conductivity survey, a general site assessment was made with respect to the specific areas within the overall grid matrix which would be the focus of additional geophysical investigations.

Ground Penetrating Radar Survey

The ground-penetrating radar equipment used was an SIR System 8 manufactured by Geophysical Survey Systems, Inc. The system consists of a control unit, transducer (radar transmitter, receiver and antenna), a magnetic tape recorder and a graphic chart recorder. The instrument operates on 12 v DC obtained from the electrical system of the support vehicle used for data collection.

Figure 1
Air Monitoring was Conducted at the Initiation of Site Activities and Throughout the Entire Project

Radar transducers operating at different frequencies yield greater depth penetration of the radar signal, while higher frequencies, although not able to penetrate the earth as deeply, give greater resolution. This greater resolution gives the higher frequency transducer the ability to discriminate between closely placed objects and interfaces. The radar signal judged best was a 300 megahertz transducer. This transducer yielded good near surface resolution while still providing adequate depth penetration.

In operation, a brief pulse of electromagnetic energy is directed into the subsurface. While this energy encounters an interface between two materials of different dielectric properties, a portion of the energy is reflected back to the transducer. The reflected energy is received by the transducer and processed within the control unit where it is amplified and the time differential between initial transmission of the electromagnetic pulse and the reception of the reflected wave is determined.

The electromagnetic wave travels through the medium at a velocity dependent upon its dielectric characteristics, so the time differential can be converted into depth. The depth versus time relationship can be established from a knowledge of the dielectric constant of the medium or, more commonly, from on-site determination of the depth of a visible radar target (soil borings). No vertical calibrations were conducted for this survey. Approximate depth determinations were made based on generalized soil parameter values. The total depth shown on the strip charts was approximately 10 ft and the detected anomalies (discussed subsequently) were within the upper 3 to 4 ft.

The electromagnetic pulse is repeated at a rate of 50 kilohertz (50×10^3 cycles per second). The data are sent to the chart recorder where a continuous record of the data is produced as the transducer is moved along the surface; data are also sent to the magnetic tape recorder where the individual return wave forms are recorded.

At the control unit, the operator has an oscilloscope display unit which continuously monitors the reflected wave form. The operator also has controls available to adjust and optimize the wave form to produce the best output on the graphic chart recorder and magnetic tape.

As with any geophysical application, the results obtained from the equipment depend on site-specific conditions. Physical conditions which affect the strength of the return signal include the amount of clay and moisture in the subsurface. In general, the site was dry, but some pockets of moisture were observed on the surface and those areas were detected by the radar. These higher moisture zones did not appear to significantly affect the system performance nor did they interfere with the overall results; however, the presence of clay did reduce the depth of penetration.

The GPR provides information only along the line of antenna tow for a width of approximately 2 ft. The antenna was manually towed along grid lines using conductive cables which connected the antenna to the control unit located in a support vehicle parked nearby. The operator provided real time interpretation of the data with the results of the GPR survey printed on a continuous roll paper copy. As signals indicating foreign bodies were observed on the paper copy, the operator in the van called out and a technician marked the suspect spot on the ground with spray paint.

DISCUSSION OF RESULTS

Terrain Conductivity Survey

A total of 804 terrain conductivity measurements were made at 419 locations over the gridded 4.6 acre area. Consistent background conductivity values were measured in the range of 70 to 90 millimho/m for the 10 ft mode and in the range of 75 to 95 millimho/m for the 20 ft mode.

The locations of the 100 millimho/m contours for 10 and 20 ft modes approximately overlap. The 400 millimho/m contour for the 10 ft mode contained most of the same contour for the 20 ft mode and is approximately twice the area. The 400 millimho/m contour for the 10 ft mode contained most of the area where exposed drums were observed.

The terrain conductivity survey showed strong conductivity anomalies at the known location of exposed drums. On this basis, it was judged probable that there were other buried objects in the region contained within the 400 millimho/m contour for the 10 ft mode.

The shapes of the 100 and 400 millimho/m contours for the 10 ft mode were similar. For the area between these contours, it was not clear if there were weaker sources of high conductivity present or if the zone of influence of strong sources (within the 400 millimho/m contour) extended to the 100 millimho/m contour. The similarity of shapes of the contours suggested that the latter might be the case. The sources of conductivity anomalies were probably present at a depth of 5 to 20 ft.

Due to soil characteristics in relation to the Geonics Limited Model EM31 conductivity meter, nothing could be stated about the presence of conductivity anomalies below a depth of 20 ft.

Ground Penetrating Radar Survey

The approximate total length of the GPR survey was 1200 ft. The GPR signals indicating the presence of a dielectric anomaly were categorized as weak or strong and as having signatures typical of a buried metal object or not.

In the grid area, 38 dielectric anomalies were identified; ten were categorized as weak signals, nine as strong signals, five as weak signals with signatures typical of buried metal objects and 14 as strong signals with signatures typical of buried metal objects. The locations of these dielectric anomalies were recorded on a plot map.

There were no vertical in situ controls (known depths of buried targets) available at the time of the GPR survey. As a result, the depths of the strong and weak signals could not be determined. Using typical soil properties, it was estimated that all identified dielectric anomalies were at a depth of 4 ft or less. Because of the presence of water and clay, the maximum depth of radar penetration reflected back to the antenna was estimated to be 10 ft or less.

Due to the operating characteristics of GPR systems, it was not possible to determine if there were any other dielectric anomalies (e.g., buried metal objects) located directly below where an anomaly was encountered.

The locations of conductivity and dielectric anomalies were shown superposed on a plot map. In the grid area, 12 of the 14 strong signals with signatures typical of buried metal objects were located within the contours of conductivity anomalies; 4 of the 9 strong signals were within the contours; 2 of the 5 weak signals with signatures typical of buried metal objects were within the contours; and 1 of the 10 weak signals was within the contours.

GEOPHYSICAL SURVEY CONCLUSIONS

Only two relatively small regions of anomalously high conductivity were found in the grid area. In one of these two areas, high conductivity was found in both the 10 and 20 ft modes. In the other area, one high reading was measured in the 10 ft mode only. The area around known locations of exposed buried drums was, for the most part, within the 10 ft mode, a very high conductivity contour.

In the grid area, the majority of the strong radar signals, including almost all of those with signatures typical of buried metal objects, occurred at locations within the contours of conductivity anomalies. Almost all the weak signals are outside these contours. Based on the results of the terrain conductivity and ground penetrating radar surveys, specific regions within the overall grid matrix were identified for confirmation as sources containing buried waste by way of test excavations.

Figure 2
Test Excavations were Conducted in Areas Which Exhibited a High
Probability of Containing Buried Wastes

Test Excavations

Areas to be initially excavated were identified both on a map as well as in the field. A crew employing USEPA Level C protective equipment utilized a 1½ yd³ tracked excavator to explore areas where buried wastes were expected based on the results of the geophysical surveys (Fig. 2). Without exception, all areas which exhibited strong anomalous characteristics were confirmed to be sources of buried drums.

The excavation gradually penetrated the soil with trenches 2 to 4 ft wide and 15 to 20 ft long until: (1) buried drums or visible contamination were observed, or (2) the test excavation trench reached a depth of approximately 15 ft where clay strata were encountered. All anomalous conditions were excavated using this trenching method.

During the excavation, it was apparent that the sources of contamination were drums buried in an area of the following dimensions: 100 ft from north to south and 50 ft from east to west at an average depth of approximately 13 to 18 ft. It was clearly evident that the drums had been haphazardly dumped into the hole as the overall integrity of the containers had decayed so that the primary waste materials encountered were distorted drum carcasses, visibly contaminated sub-soils and miscellaneous pint and quart size paint cans. Standing water, which was apparent approximately 4 ft below the surface, engulfed the entire 50 ft x 100 ft burial site.

During the initial excavation phase, field technicians wearing USEPA Level B protective equipment obtained samples of drum residues, surrounding soil and groundwater for analysis (Fig. 3).

Samples obtained during the test excavations contained the following compounds:

Methanol	Toluene
2-Ethoxyethanol	3-(1,1-Dimethylethyl) Phenol
Ethylbenzene	Naphthalene
Xylene	Benzene
Propylene Glycol	Phenol

Fifteen test excavation pits were dug on the site, clearly establishing the physical parameters of the burial trench. Approximately 65 crushed and empty drum carcasses could be identified; however no materials were removed from any test pits once waste was encountered. Therefore, the exact number of buried drums could not be ascertained; only the boundary limits of the disposal area were established.

The remedial investigation provided the working information required to begin development of a remedial action plan to remove wastes from the site; however, the limits of soil contamination outside the identified burial trench needed to be established due to the potential of contaminant transport through the soil.

Figure 3
Technicians Secured Residue Samples for Analytical Testing
and Identification

Multiple Soil Borings

To determine whether there had been migration of buried wastes into the surrounding soils, 44 holes were drilled radially around the burial trench. The outer ring of the boring was 150 ft from the corner points of the burial trench. The holes were drilled using a drill rig mounted on an all-terrain vehicle. Soil samples were obtained using either a split spoon or an auger. The sampling spoon and/or auger were decontaminated after each boring was made.

In general, each of the soil borings revealed a surface layer of granular materials consisting primarily of sand and gravel, at depths ranging from 3.0 ft below present grade to 8.0 ft below grade. Each of the soil borings drilled in this exploration was terminated in soft to hard silty clays, the majority of which were from 10 to 30 ft thick. From the field boring data, it was determined that the clay layer was a continuous strata existing across the limits of the exploration.

Interpretation of water activity below the site was accomplished through real time measurement of water levels in the 44 bore holes just after development and 24 hr later. Although this did not provide the exacting data which could be generated through piezometer studies, the relative relationship between the water level in the different holes showed that the variance in water level was only ±0.2 ft across the entire area where holes were drilled. This minor variation, given the protocol employed, resulted in a conclusion that the water associated with the burial trench had a high probability of being perched or at least had a very low rate of transport; this conclusion is plausible given the underlying soil conditions. The mere presence of the underlying water necessitated that it be adequately addressed in formulating the remedial action approach for removal of the wastes.

Statistically selected samples from various depth intervals from the 44 borings were analyzed to detect contaminants within and outside of the burial zone. There was no contaminant transport away from the source. Contaminants detected in samples of soil from within the burial trench were of a character similar to those compounds identified during the test excavations.

REMEDIAL ACTION PLAN

The remedial investigation provided valuable data for development of a remedial action plan. At the conclusion of the exploratory activities, the following investigative objectives were met:

- Given the geophysical capabilities of the methods employed during the investigation, the source of buried wastes within the area of concern was isolated to a burial trench which had approximate dimensions of 50 ft x 100 ft x 15 ft.
- The area which had buried wastes removed during an excavation seven years earlier resulted in negative findings with respect to the various geophysical surveys.
- Upon defining the burial trench, soils beyond the perimeter of this trench tested free of contaminant transport attributable to the buried wastes.
- An identification of water encircling the site was made during drilling activities.
- Analysis conducted on buried wastes provided the data necessary to specify treatment/disposal alternatives.
- The volume of contaminated soils and drum carcasses was estimated at 2,450 yd³ ± 250 yd³.

Following a detailed analysis of the data developed during the investigation, a remedial cleanup approach and budgetary estimate was formulated for review by the County Board of Commissioners. The highlights of the remediation plan included:

- Complete removal of contaminated solids (soils and drum carcasses) from within the boundaries of the identified waste burial trench down to the interface of the underlying clay strata
- Containment of contaminant transport during remedial activities through the development of a barrier wall to encircle the area to be excavated
- Environmental health and safety protocols including a contingency program to be in effect during the cleanup effort

• Disposal of identified waste materials at a permitted secure chemical waste TSDF
• Specifications for the aforementioned remedial approach

Upon recommendation by the County task force responsible for evaluating the environmental situation facing the Conservation District, the Board of Commissioners voted to proceed with site mitigation activities at the sand and gravel quarry. The Conservation District would finance 100% of the cleanup by employing usury funds generated through the commercialization of the quarry; therefore, no tax monies or special funding provisions would be required to remove the wastes. Within five days from the Board's authorization to proceed with the cleanup, a remedial action contractor had been selected with mobilization of personnel and equipment initiated.

SITE MITIGATION

Prior to actually removing the identified waste materials from the burial trench, it was necessary for the on-site contractor to construct a 360° barrier wall as a means of controlling potential contaminant transport away from the trench.

Numerous cut-off wall alternatives would meet the objectives of the project; however, the selected approach would require rapid installation while still providing the necessary restriction of potential contaminant transport. It was decided that, due to the schedule required to exhume the wastes (six to ten days) and the knowledge that the burial trench area sat on top of a continuous clay layer, the most efficient and cost-effective technique would be a synthetic barrier wall.

The synthetic barrier wall installation was straightforward. Based on results of soil analyses conducted during the geophysical surveys, a trench approximately 4 ft wide was excavated around the entire burial site. The trench placement was made at a distance of 5 to 10 ft from the known boundaries of the burial trench and to an average depth of 20 ft (approximately 2 ft into the underlying clay strata).

During excavation of the trench, which would contain the synthetic barrier wall, the installation field crew fabricated the 80 mil high density polyethylene (HDPE) so it could be conveniently fitted into the awaiting trench. Installation of the HDPE liner necessitated that standing water, which infiltrated the trench, be removed prior to installation of the synthetic barrier. The liner was lowered into the trench so that a "U" shaped envelope was created; this envelope was keyed to the subsurface clay strata. Upon completion

of the liner placement, imported clay backfill was introduced into the liners envelope, effectively cutting off the waste burial trench from the surrounding uncontaminated areas.

In addition to the barrier wall, a waste staging and loading pad was constructed and lined with 80 mil HDPE, thus creating an exclusion zone which would be protected from cross contamination of clean areas with the waste materials.

Upon completion of site preparation, upwind and downwind air monitoring stations were positioned. A personnel decontamination facility, field command post and a vehicle decontamination area and tarping station were also established.

Actual removal of the contaminated soils and drum carcasses required only seven working days, during which time 200 loads of hazardous wastes were removed and transported to a permitted chemical waste disposal facility. In addition to the contaminated solids encountered, it was necessary to remove several tanker loads of potentially contaminated water which had infiltrated the excavation trench. Once the wastes had been excavated and removed, the barrier wall was left intact while the staging and loading pad and associated materials were removed and disposed of off-site at a permitted facility. Backfilling and grading of the excavation trench with imported clay was accomplished subsequent to the site mitigation.

CONCLUSIONS

The presence of uncontrolled hazardous wastes continues to create environmental concerns throughout the United States. Buried wastes present unique problem-solving situations, and this project exhibits just one possible approach to the solution of an environmental problem. As more and more abandoned hazardous waste sites are discovered, there will be an increasing need for a developing industry to provide technologies and methodologies to safely deal with these concerns. ENRAC is pleased to have worked on this project and to have increased its firsthand knowledge in this type of mitigation work as it strives to become a more experienced and important factor in the emerging site mitigation segment of the hazardous waste industry.

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GUIDELINES FOR DECONTAMINATING BUILDINGS, STRUCTURES AND EQUIPMENT AT SUPERFUND SITES

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INTRODUCTION

CERCLA established a dual-phase program for responding to environmental problems caused by hazardous substances. The "removal program" involves cleanup or other actions taken in response to emergency conditions or on a short-term or temporary basis. The "remedial program" involves response actions that tend to be long-term in nature and permanently remedy problem sites.

To be eligible for cleanup under Superfund, a site must be included on the National Priorities List (NPL). As of this writing, 406 sites appear on the NPL which was promulgated by the USEPA on Sept. 8, 1983. Currently, the USEPA is proposing the addition of 133 new sites to the list.

As the number of sites on the NPL grows and as removal and remedial activities at Superfund sites accelerate, the task of decontaminating buildings, structures and construction equipment will become increasingly important. These items often represent large capital investments, and the costs of dismantling and disposing of such structures in a secure landfill can be very expensive. The objective of an effective decontamination program, therefore, is to return contaminated buildings, structures and equipment to active, productive status.

This study had as its goal the development of a general guide for government personnel, cleanup contractors and other individuals responsible for planning and executing decontamination activities at Superfund sites.

TECHNICAL APPROACH

In the fall of 1983, a survey was made of ongoing decontamination activities at 50 Superfund sites across the country. These sites were thought to have potentially contaminated buildings, structures and equipment, and this survey was conducted to gather information on: (1) the types of contaminants of most concern and (2) the methods currently being proposed for use for decontamination of the buildings, structures and equipment in place at these sites. Contractors and numerous other individuals with direct experience in both Superfund and non-Superfund related programs involving decontamination of dioxins, explosives, PCBs and other toxic wastes from buildings and equipment were contacted. In addition, a thorough search of published literature for information on decontamination methods was conducted through computerized search services.

From these surveys, a decontamination data base containing state-of-the-art information on specific cleanup methods and their applications, as well as guidelines for developing site-specific cleanup strategies, was developed.

RESULTS

The 1983 survey of building/equipment decontamination practices at Superfund sites revealed that the contaminants of most concern at these sites included: asbestos, acids and alkalis, dioxins, explosives, heavy metals, cyanides, low-level ionizing radiation, organic solvents, pesticides and PCBs. The methods used to remove these substances from buildings, structures and equipment are few in number and rarely documented in detail. For example, it is common practice to steam clean equipment such as backhoes, bulldozers and drilling augers, but testing to verify that the contaminants of concern have been adequately removed is generally not performed.

Contaminated buildings and structures are seldom cleaned and returned to active use. More often, they are closed and barricaded to prevent further entry and exposure until sometime in the future when a solution regarding their deposition can be found. Some buildings are torn down and buried in landfills. Contaminated underground structures such as tanks, sumps and sewers are sometimes filled in place with concrete to prevent their reuse.

Because these findings clearly pointed to the need for basic guidance material on decontamination methods, the remainder of the project was devoted to developing a manual or user's guide for this purpose. The handbook which was developed presents general guidelines for developing a rationale and strategy (Fig. 1) for dealing with the prospect of decontamination including guidance and information for selecting the least-costly method(s) that are technologically feasible and that will effectively reduce contamination to predetermined levels. Steps in the process include: (1) determining the nature and extent of contamination; (2) developing and implementing a site-specific decontamination plan; and (3) evaluating decontamination effectiveness.

Step 1
- Querying former employees, searching old business records, inspection reports and news stories
- Conducting a visual site inspection
- Collecting and analyzing samples from the contaminated surfaces or structures.

Step 2
- Identifying the future intended use of buildings, structures and equipment
- Establishing decontamination target levels for the contaminants present
- Identifying and evaluating potential decontamination methods
- Selecting the most appropriate method(s) for achieving the decontamination target levels

Figure 1
Flow Diagram Illustrating Sequence of Steps for Developing a
Decontamination Strategy

The flow diagram contains the following boxes:

Left column:
- DETERMINE NATURE AND EXTENT OF CONTAMINATION
- DEVELOP AND IMPLEMENT SITE-SPECIFIC DECONTAMINATION PLAN
- EVALUATE DECONTAMINATION EFFECTIVENESS

Right column:
- QUERY FORMER EMPLOYEES
- SEARCH OLD BUSINESS RECORDS, INSPECTION REPORTS, AND NEWS STORIES
- CONDUCT VISUAL SITE INSPECTION
- COLLECT AND ANALYZE SAMPLES
- IDENTIFY FUTURE INTENDED USE OF BUILDINGS, STRUCTURES, AND EQUIPMENT
- ESTABLISH DECONTAMINATION TARGET LEVELS FOR CONTAMINANTS PRESENT
- IDENTIFY AND EVALUATE POTENTIAL DECONTAMINATION METHODS
- SELECT MOST APPROPRIATE METHOD(S) FOR ACHIEVING DECONTAMINATION TARGET LEVELS
- DETERMINE WORKER HEALTH AND SAFETY REQUIREMENTS
- WRITE SITE DECONTAMINATION PLAN
- HIRE CONTRACTOR AND INITIATE CLEANUP
- REINSPECT SITE
- COLLECT AND ANALYZE SAMPLES
- DETERMINE WHETHER TARGET LEVELS HAVE BEEN REACHED
- REPEAT OR MODIFY DECONTAMINATION PROCEDURE AS NECESSARY

•Determining worker health and safety requirements (training, medical surveillance, personal protective equipment, site safety)
•Writing the site decontamination plan
•Estimating costs
•Hiring the contractor and initiating cleanup

Step 3

•Reinspecting the site for evidence of residual contamination
•Collecting and analyzing samples from the decontaminated area
•Determining whether the target levels for residual contamination have been reached
•Repeating and, if necessary, modifying the decontamination procedures until satisfactory results are obtained

Descriptions of actual building decontamination efforts at both Superfund and non-Superfund sites are included as case studies in the report.

The manual contains process descriptions for 21 decontamination methodologies including both traditional and developmental techniques (asbestos abatement, absorption, demolition, dismantling, dusting/vacuuming/wiping, encapsulation, gritblasting, hydroblasting/waterwashing, painting/coating, scarification, RadKleen, solvent washing, steam cleaning, vapor-phase solvent extraction, acid etching, bleaching, flaming, drilling and spalling, K-20, microbial degradation and photochemical degradation). The usefulness of each cleanup method with various combinations of contaminants and materials is given.

Potential cleanup methods are identified in a two-dimensional matrix (Table 1) matching contaminants (asbestos, acids, alkalis, dioxins, explosives, heavy metals and cyanides, low-level radiation, organic solvents, pesticides, PCBs and all contaminants in liquid form) with materials/surfaces (all wall, ceiling and floor surfaces; glass; plastic; metal; wood; brick; concrete; aluminum; and equipment and auxiliary structures).

Finally, the manual describes safeguards for protecting the health and safety of decontamination workers during site operations. Topics covered include personnel training, medical surveillance, personal protective equipment and site safety.

CONCLUSIONS AND RECOMMENDATIONS FOR ADDITIONAL RESEARCH

As a result of this study, it has become clear that all future owners of decontaminated buildings and structures on Superfund sites

Table 1
Potential Decontamination Methods for Various Contaminant/Material Combinations[a]

Material/surface	Contaminant										
	Asbestos	Acids	Alkalis	Dioxins	Explosives	Heavy metals and cyanide	Low-level radiation	Organic solvents	Pesticides	PCB's	All contaminants in liquid form
All wall, ceiling, and floor surfaces	1,3,4,5	3,4,6,9,16	3,4,6,9	3,4,5,6,9,21	3,4,6,9,13	3,4,5,6,8,9,16	3,4,5,6,9	3,4,6,9	3,4,6,9,13	3,4,5,6,9	?
Glass	1,3,4,5	3,4,6,9,16	3,4,6,9	3,4,5,6,9,21	8,16	3,4,5,6,8,9,16	8	3,4,6,9	16	3,4,5,6,9	?
Plastic	1,3,4,5	3,4,6,9,16	15	15	8,15,16	15	8,15	15	15,16	15	?
Metal	1,3,4,5	7	7,15	7,15	7,8,15,16,17	7,15	7,15	7,8,15	7,15,16	7,15	?
Wood	1,3,4,5	7	7,15	7,15	7,15,16,20	7,15	7,15	7,15	7,15,16,20	7,15,19	?
Brick	1,3,4,5	7	7,15	7,15	7,8,15,17,20	7,15	7,15	7,8,15	7,15,20	7,15,19	?
Concrete	1,3,4,5	7,10,18	7,10,15,18	7,10,15,18	7,8,10,15,16,17,18,20	7,10,15,18	7,10,15,18	5,7,8,10,15,17,18	7,10,15,18	7,10,15,16,18,20	7,10,15,18,19	?
Equipment and auxiliary structures (bulldozers, electrical transformers and capacitors, sumps, ventilation ducts, etc.)	1,5	4,6,11,12,13	4,6,11,12,13	4,5,6,11,12,13,21	4,6,8,11,12,13,17	4,5,6,7,8,11,12,13	4,6,8,11,12,13	4,6,11,12,13	4,6,11,12,13	4,5,6,11,12,13,14	?

Key for decontamination methods:
1. Asbestos abatement
2. Absorption
3. Demolition
4. Dismantling
5. Dusting/vacuuming/wiping
6. Encapsulation
7. Abrasive gritblasting
8. Hydroblasting/waterwashing
9. Painting/coating
10. Scarification
11. RadKleen
12. Solvent washing
13. Steam cleaning
14. Vapor-phase solvent extraction
15. Acid etching
16. Bleaching
17. Flaming
18. Drilling and spalling
19. K-20 coating
20. Microbial degradation
21. Photochemical degradation

Each cell in the matrix represents a specific contaminant/substrate combination and contains numbers corresponding to decontamination methods that either have been used in the specific interactions, or have the potential for such use, based on available information in the published literature. Each methodology can be used alone or in conjunction with one or more of the other procedures.

should be advised of the nature of the contamination that was present, the cleanup methods used and levels of any residual contaminants. Ensuring the transfer of such information from one site owner to the next will require a method for permanently recording this information. Regulations requiring the addition of such information to the property deed, as is required in the deed of all RCRA-permitted facilities, may be a workable solution.

The handbook which was developed will provide much of the guidance needed by site cleanup personnel for decontaminating buildings, structures and equipment. However, additional research is needed to bridge gaps in the state of the art in four key areas. First, and perhaps most importantly, sampling methods for determining the type and degree of contamination existing on building/structure/equipment surfaces, both before and after cleanup efforts, are poorly developed, documented and verified. Similarly, subsurface sampling techniques (such as corings) for determining the depth of contamination in porous substances (such as concrete or wood floors) have not been adequately developed and documented. Although "wipe tests" are often referred to, in site records, the actual methodology used is rarely described in enough detail to allow simulation or reproduction by others, and the technique itself is known to be inadequate for quantitatively transferring contaminants from surfaces to wipes or swabs. Additional research in this area is badly needed.

Second, many of the decontamination techniques described in the manual were developed specifically by the U.S. Army's Installation Restoration Program. Their applicability to contaminant/material combinations encountered at Superfund sites has not been fully explored. Even where decontamination techniques are indicated for certain contaminant/material combinations, the more detailed methodology descriptions should be consulted for any future work that may be required before the methods are selected.

Third, the effectiveness of many decontamination methods currently in use has not been verified and documented. For example, the degree to which steam cleaning removes dioxin-contaminated soil particles from drilling augers has not been established. Decontamination methods that have not previously been applied to specific contaminant/substrate combinations but show a strong potential applicability should be validated in pilot investigations. Additions/deletions to the matrix should be made accordingly. New decontamination technologies that become available also should be evaluated and added to the matrix.

Fourth, a formal, systematic approach for determining acceptable levels of contaminants remaining in and on building and equipment surfaces does not currently exist. As a result, guidance on the "How clean is clean?" issue and the establishment of target levels could not be included in this manual and must continue to be addressed on a case-by-case basis.

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CONTINGENCY PLANNING FOR REMEDIAL ACTIONS AT HAZARDOUS WASTE SITES

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INTRODUCTION

Upon inclusion of a hazardous waste site on the National Priority List, various planning and design activities are initiated before remediation of the site commences. During the planning and design phases, relatively few people are involved and their health and safety are protected through well defined measures specified in Health and Safety Plans. However, during the actual remedial work phase at a hazardous waste site, the health and safety concerns of an entire community have to be addressed in a Contingency Plan. It is possible that emergency situations might arise during remedial construction which would require the coordinated efforts of the contractor, local, state and Federal authorities to cope with the situation.

In this paper, the authors discuss two contingency plans developed by the USEPA Region II for the Bridgeport Rental and Oil Services (BROS) site and the Lipari Landfill site, both sites located in Gloucester County, New Jersey. In these plans, the USEPA staff identified potential incidents which could impact the health and safety of the nearby community, who should be called upon to respond to these incidents, hazardous substances present at the site, specifications of action levels in order to determine the point at which the contingency plan should be activated and the type of response action that should be taken.

BRIDGEPORT RENTAL AND OIL SERVICES SITE

The BROS site covers approximately 30 acres in Logan Township, Gloucester County, New Jersey. The site is a tank farm consisting of 90 tanks and process vessels, drums, tank trucks and a 12.7 acre waste oil lagoon. The lagoon has an oily layer, aqueous phase and bottom sludges.

The USEPA began remedial measures in the summer of 1983. This initial remedial work consisted of lowering the level of the lagoon by approximately 10 ft by removing 35 million gal. This removal was accomplished by treating the aqueous phase of the lagoon and discharging it to Little Timber Creek. This action was taken to prevent the lagoon from overflowing its dike and to stabilize the site until implementation of the long term cleanup program.

During implementation of the initial remedial measure, a mobile treatment system was constructed on-site. The treatment system consisted of an oil/water separator, flocculation-sedimentation and sand and granular activated carbon filtration. Various lagoon waste pumping systems were installed as well as fencing, decontamination, personal hygiene and emergency medical facilities, etc.

The contractor performing this work prepared a health and safety plan for his personnel. However, due to unpredictable circumstances, a situation could have arisen where the air or surface water in the vicinity of the site could have been contaminated. Such a situation would have been beyond the control of the cleanup contractor. The incident might have required the help and cooperatioan of local, county, state and Federal authorities to correct the situation.

Therefore, a contingency plan was developed in conjunction with all potential response participants. Part of the contingency plan was devoted to preparing a telephone roster of the potential responding participants as well as area hospitals. In addition, based on the various physical characteristics of the site, the chemical characteristics of the lagoon (Table 1) and the type of work being undertaken at the site, contingencies were planned for the following three emergency situations: Fire/Explosion, Air Quality Deterioration and Water Quality Degradation.

Fire/Explosion

A fire on the site would have been handled by the local fire department with support given by other local fire departments and area oil refinery fire fighting crews if necessary. Also supporting this response would have been the contractor personnel who would have taken appropriate measures to restrict the fire on site before the fire department arrived. USEPA would have provided technical assistance and additional air monitoring during this episode.

During the preparation of the Contingency Plan, discussions were held with the Fire Department and representatives of Logan Township. During those discussions, it was determined that the Fire Department had neither the appropriate equipment to adequately respond to this situation nor familiarity with the chemicals at the site.

In response to their concerns, the USEPA provided foam generating equipment and self contained breathing apparatus (SCBAs) to supplement the local Fire Department's supply (this equipment is intended to be used at other Region II Superfund sites after completion of the current project). The Contingency Plan also provided a list of the most significant chemicals and their concentrations (See Table 1), their hazard potentials, harmful effects, exposure limits, etc.

Air Quality Deterioration

Due to the various chemicals known to be present at the site and the unknown nature of the material exposed as the lagoon was lowered, it was felt that a situation could arise which could cause the air quality to deteriorate both on- and off-site.
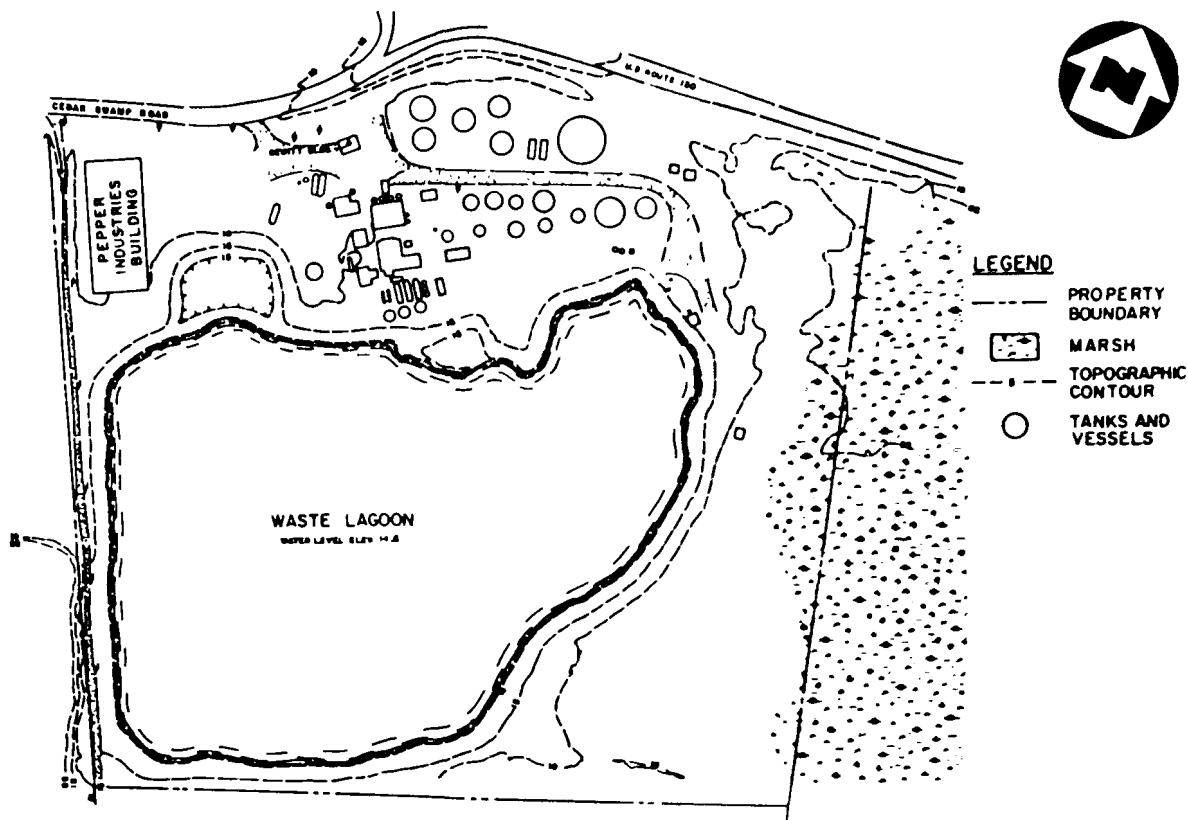
Figure 1
General Site Arrangement
Bridgeport Rental & Oil Services, Logan Twp., NJ

As part of the health and safety plan, the contractor was required to take air monitoring readings at intervals of every 4 hours using an HNU photoionization detector. Periodically, Tenax or charcoal tubes were utilized to measure air quality. If the air quality at the perimeter of the site rose to 3 ppm above background for 15 min, as measured by the HNU, the contractor would begin measuring the air quality in the direction of the residents at locations 500, 3500 and 500 ft from the site in succession.

Once this off-site monitoring commenced, Federal authorities would advise the County Emergency Management Coordinator of the situation and prepare to take action if needed. If the air quality at the off-site locations deteriorated to 3 ppm for 15 min above background, a recommendation would be made to the County Emergency Management Coordinator to advise the residents of the affected area to go into their homes and shut windows, doors, etc.

If the air quality deteriorated to 5 ppm for 15 min above background, a recommendations would be made to the County Coordinator to evacuate the homes. Names, addresses and phone numbers of the citizens living hear the site were provided in the contingency plan.

However, any actual evacuation decision would be made by the local authorities. Also, local authorities would actually manage the evacuation. The USEPA would provide technical assistance to the local officials as well as extensive air monitoring to assess the hazard and be in a position to recommened additional actions.

The action levels specified for recommending evacuation of homes were based on the USEPA's *Interim Standard Operating Safety Guide*. The manual recommends that SCBAs be worn when total vapor concentrations exceed 5 ppm as measured by instruments such as an HNU Photoionizer. Obviously, as more information on the specific type of contamination was gathered, the situation and previous decisions could be reassessed. The use of 3 ppm above background as an action level to begin taking precautionary measures was primarily based on conversations with members of various emergency response organizations.

Water Quality Degradation

As previously mentioned, the BROS lagoon's aqueous phase was pumped, treated and discharged into a nearby stream, Little Timber Creek. Therefore, a potential existed for treatment process

Table 1
Major Organic Chemicals Found in BROS Lagoon

Parameters	Oil Phase	Ave Concentrations
PCB		667 ppm
Ethylbenzene		25 ppm
Toluene		57 ppm
	Aqueous Phase	
Napthalene		114 ppb
Acenapthalene		11 ppb
Phenol		590 ppb
Benzene		378 ppb
1,1,1 Trichloroethane		214 ppb
Ethyl Benzene		196 ppb
Tetrachloroethane		20 ppb
Toluene		1394 ppb
Tricholorethene		87 ppb
Bis-2-chloroethyl-ether		29 ppb
1,2 Dichloropropane		110 ppb
Di-ethylphthalate		493 ppb
Chlorobenzene		11 ppb
		85 ppb

failure and untreated discharge being released into the stream. Also, a failure or rupture of one of the on-site tanks could cause a release of contaminants to surface waters adjacent to the site.

Upon detection of the discharge, the Corps of Engineers (COE) resident engineer would notify the USEPA, State and County Health Department.

These agencies would assume the responsibility for implementing measures to ameliorate, if possible, the contamination caused by the spill and provide recommendations for further action. Also, signs would be erected along the stream warning the public that the stream had been contaminated and that contact with the water should be avoided.

LIPARI LANDFILL

The Lipari Landfill site (Fig. 2), occupies approximately 16 acres of a former gravel pit in the Township of Mantua, Gloucester County, New Jersey. Between 1958 and 1971, household wastes, liquid and semi-solid chemical wastes and other industrial waste materials were buried there.

The site is bordered on two sides by two streams, Chestnut Branch and Rabbit Run, which converge near the landfill and enter Alycon Lake approximately 1000 ft downstream of the site. Most of the land area surrounding the landfill is occupied by fruit tree orchards and agricultural land. However, a housing development of single family occupied homes is located approximately 500 ft from the northern boundary of the landfill. Some of the chemicals found in the leachate on the site are listed in Table 2.

As part of the first phase of cleanup at the site, a contract was awarded to construct a leachate containment system to encapsulate the contaminated area of the site. The system consisted of a soil bentonite groundwater cut-off wall, a synthetic membrane cap with protective earth cover and a gas venting system. Other ancillary work included provisions for a support area, security and decontamination operations, personal hygiene facilities, emergency medical facilities, etc.

Table 2
Organic Chemicals Found in Leachate of Lipari Landfill

Parameters	Concentration Range (ppb)
Bis (2-chloroethyl) ether	440-210,000
Toluene	51-22,400
Phenol	490-100,000
Benzene	9.8-2,012
Ethyl Benzene	62-1,600
Methylene Chloride	.7-88
Chlorobenzene	11-106
Bis (2-ethylexyl) phthalate	12-120
1,2-Dichloethlyene	43-5,800
Diethylpthalte	2.4-28
1,1-Dichloroethlyene	4.4-36
Trans-1,2-Dichloroethlyene	2.4-28
Naphthlene	5.7-102
1,1, Dichloroethane	5.2-150
Trichloroetylene	0.9-23
Acrolein	0-16
Bis (2-chloroisoproplether)	0-80
Chloroethane	3-34

Due to the chemicals present, existing conditions and the type of work being performed at the site, it was felt that the only potential hazards which the contingency plan should address were air quality deterioration and fire.

Air Quality Deterioration

Due to the trenching operation required for the construction of the slurry wall, there was a possibility of releasing volatile chemicals which could migrate off-site into a residential area. This danger was believed to be especially critical when trenching approached highly contaminated areas in the landfill which were closest to homes.

As part of the contractor's health and safety plan, he was required to place several Tenax tube air monitoring stations around
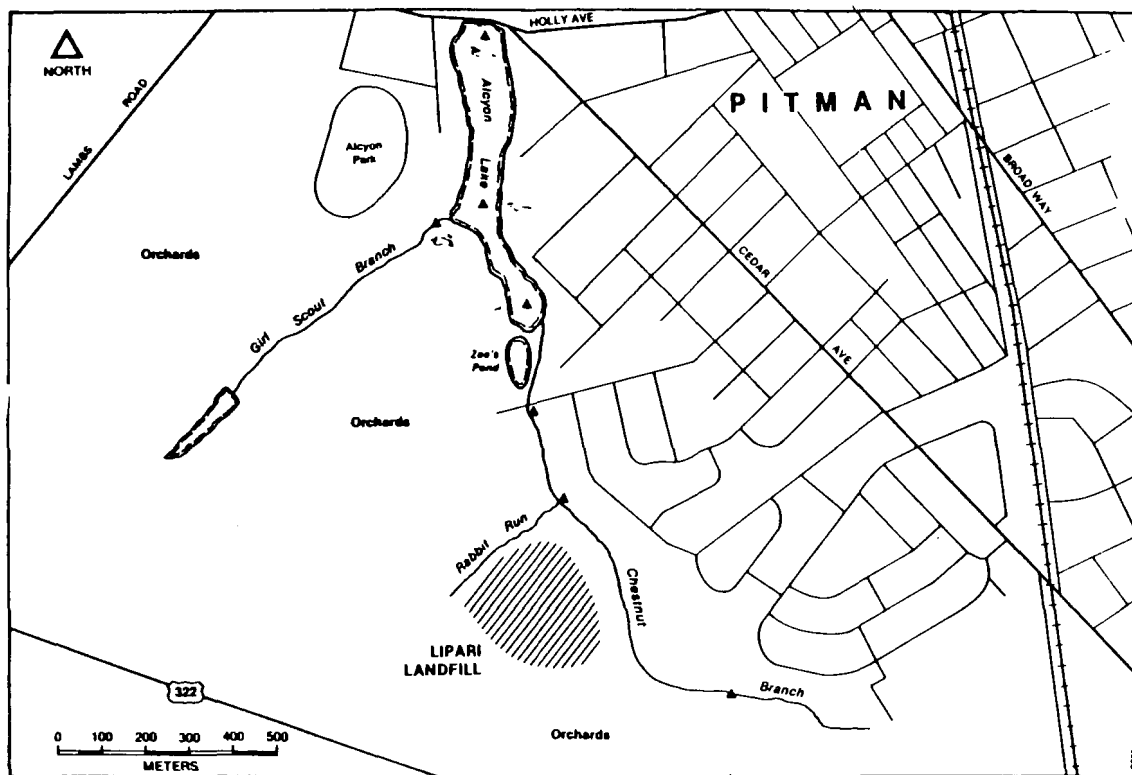
Figure 2
General Location of Lipari Landfill
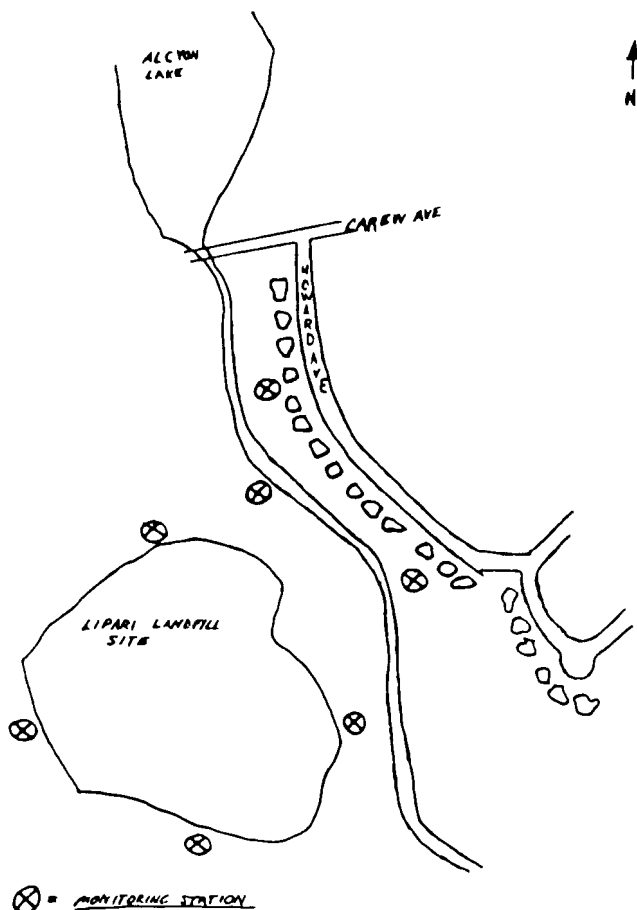
Figure 3
Air Monitoring Station Locations

the periphery of the site. These air monitoring stations were designed to collect samples daily, but the samples were not analyzed. In addition, monitoring stations were located off-site in the marsh area between the site and the nearby residences.

Also, the contractor monitored the air quality continuously at all active work locations with an HNU photoionization detector. If readings of 10 ppm or greater at the on-site active work area were detected, the perimeter Tenax tube samples would be analyzed. In addition, HNU detectors would be moved to downwind perimeter and off-site locations (Fig. 3).

The off-site sampling locations were situated near the residential homes. If total organic vapor concentration readings at the site perimeter locations exceeded limits similar to those set at the BROS site, the County Emergency Management Coordinator would be advised by the USEPA or its representative of the situation and a recommendation would be made to him to advise the residents to remain indoors, close windows, etc. The County Emergency Management Coordinator was advised to keep a list of the names and phone numbers of the potentially affected residents.

If these same total organic vapor concentrations limits were detected at the off-site locations, then the Emergency Management Coordinator would be advised to evacuate the affected residences. Similar to the BROS site, after analyses of the Tenax tubes, more specific information on the air contamination would be available and the situation would be re-examined. The actual notification, evacuation decision and evacuation would be performed by local authorities. In addition, the USEPA and the State would provide continuous air monitoring as well as technical assistance to the local authorities until the situation was remedied.

Fire

Fire was deemed a possibility at this site. Construction equipment, fuel storage and the possibility of striking a flammable substance during the trenching operation presented potential problems. Similar to the BROS situation, the local Fire Department would be notified and take command of the situation. Also, the additional SCBA units and fire fighting foam stored at the BROS site would be transported to the Lipari Landfill (approximately a 15 min driving distance) for the Fire Department's use. The USEPA and State authorities would be made available to provide technical assistance.

CONCLUSIONS

Contingency planning is an essential activity that must take place prior to the initiation of remedial action at a hazardous waste site. Contingency plans must clearly delineate the potential emergencies which may occur on- or off-site and identify various response participants roles in these emergencies.

One critical aspect in contingency planning is to make certain that all participants are educated on the potential emergencies and hazards present at the site. In addition, it is critical to assess the response participants' capabilities to determine whether they are prepared to respond or whether additional equipment, information, etc. should be made available to them.

By August, 1984, the majority of the work at the BROS site and Lipari Landfill had been completed. Fortunately, there has not been a need to activate the contingency plans. However, careful planning, including a partial testing of one of the plans, at these sites would have provided for a well coordinated response.

SELECTING SUPERFUND REMEDIAL ACTIONS

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INTRODUCTION

The fourth year of the Superfund program has been marked by a shifting in the emphasis of USEPA activities at uncontrolled hazardous waste sites. During the initial years, the USEPA's primary goal was to identify the worst uncontrolled hazardous waste sites, investigate the nature and content of the problem at high priority sites and evaluate appropriate remedial actions. As of July 31, 1984, the USEPA has funded remedial investigations and feasibility studies (RI/FS) at 258 National Priorities List (NPL) sites. As States and the USEPA Regions complete these RI/FS projects, the Superfund program is shifting from the initial study phase to the cleanup phase. The USEPA has already approved remedial action projects for the cleanup of numerous sites. As of July 31, 1984, for the entire Superfund remedial program, which includes Fund-financed and private party response, there have been 134 cleanup actions approved at NPL sites.

The National Contingency Plan (NCP) defines three types of remedial actions.
• Initial Remedial Measures (IRMs)
• Source control measures
• Off-site measures

Currently, the USEPA's Regional Administrators have the authority to initiate all planning activities and to select initial remedial measures, but source control and off-site measures must be approved by the Assistant Administrator for Solid Waste and Emergency Response at USEPA Headquarters. Before a remedial action is approved, the USEPA conducts a thorough technical, policy and legal review of the recommended project to ensure that NCP and CERCLA requirements have been met.

PURPOSE

A variety of technical information is required to select remedial actions. As USEPA's experience expands in this area, the information needs should become better defined. This paper identifies several of the key technical requirements needed before the State and USEPA can select the appropriate remedial action.

The key to good decision-making is the remedial investigation and feasibility study. The RI/FS is the single document that both identifies the nature and extent of contamination at the hazardous waste site and evaluates feasible alternatives to remedy the site problem. It is essential that the RI/FS contain information that is adequate, both in quality and quantity, to allow selection of the correct remedial action. The quality and timeliness of the remedial investigations and feasibility studies generally have not been adequate. Too often, RI/FS projects take too long, present insufficient data, lack key alternatives and do not provide sufficient evaluation or rationale for the alternatives.

Because of this problem, too many RI/FSs have to be modified by the State or the USEPA, causing delay in selection of a remedial action. Some of the common problems encountered are:
• Likely alternatives are not identified early in the RI process
• Data are only minimally adequate
• The no-action alternative is not fully evaluated
• Incomplete cost estimates
• Alternatives presented by outside groups are not evaluated
• On-site RCRA landfill requirements and groundwater correction requirements are not evaluated

The USEPA has developed guidance documents on remedial investigations and feasibility studies that will avoid future problems of this type. The Agency is also completing its policy on the applicability of other environmental acts to CERCLA actions. Finally, the USEPA is preparing a series of guidance documents relating to specific types of remedial actions. This series will begin with drums and tanks, surface impoundments and provision of potable water.

This paper discusses some key data and analytical requirements for both remedial investigations and feasibility studies needed before remedial actions can be approved by the USEPA.

REMEDIAL INVESTIGATION

The purpose of a remedial investigation is to define the nature and extent of contamination at a site to the extent necessary to evaluate, select and design a cost-effective remedial action. At most sites, it would be prohibitively expensive to completely define the nature and extent of contamination with 100% certainty. However, the data collected must be sufficient to support an engineering evaluation of remedial alternatives. Unfortunately, many current RIs are not focusing data collection properly; as a result, costs are high and studies lack specific detail to support the key remedies.

The first step in an effective remedial investigation is to scope the boundary of the project, identify the problems posed by the hazardous substances and begin defining the type of remedial action required. If hazardous substances are still at or near the location of original disposal, the RI/FS needs to focus on and evaluate potential measures to control the source of contamination (source control measures). If the hazardous substances have migrated away from the original area, then measures must be developed to deal with the contamination that has migrated in the environment (off-site measures). In some cases, an RI/FS may address both types of actions.

Key Data Needs

Needed for source control measures is a definition of the horizontal and vertical extent of on-site contamination. This definition is necessary to determine how much control is required to prevent or minimize migration of the contamination from the site.

In some cases, the areas of contamination are easily defined. For example, surface impoundments usually have distinct boundaries. The impoundment can be defined in terms of volume and dimension and the waste characteristics identified. The impoundment must also be investigated to determine if liquids have stratified; if so, volume and characteristics of each layer must be evaluated. This may significantly affect the development of remedial alternatives. For example, at one site, a layer of vinyl chloride was found at high enough levels to volatilize when exposed to the atmosphere. This knowledge imposed a significant constraint on the alternatives for dewatering and treatment of the wastes.

Buried solid wastes or drums and tanks present different source control problems. The residual contamination that has migrated into the soil adjacent to these more concentrated wastes is more difficult to define and evaluate. The boundaries of contamination are usually not distinct; rather, the contamination varies with distance from the source. A profile of the concentration of these contaminants must be determined by sampling soil at various distances from the source. Soil borings, test pits or other appropriate techniques should be utilized and the samples analyzed to allow extrapolation of contamination profiles to background conditions. Soil sampling may be stopped at the water table if additional actions are proposed to address contaminated groundwater; however, samples taken in the saturated zone are essential in evaluating alternative groundwater control or treatment methods.

The analysis of soil contamination must show the relationship of vertical and horizontal distance to concentration and volume of contaminated material. This analysis is necessary to ensure that the data are adequate to evaluate a reasonable range of remedial alternatives.

As with measures addressing the source of contamination, a primary function of a remedial investigation for contamination that has migrated into the environment is to define the vertical and horizontal extent of contamination. The most significant problem in this area is contaminated groundwater which generally has a greater areal extent but less varied concentration than source contamination. Typically, more extensive data collection is needed to adequately define the extent of off-site contamination. Whereas with source control measures the analysis of hydrogeologic conditions is usually qualitative, the analysis must be quantitative when a contaminated groundwater plume is being evaluated. The objective is not only to quantify the source, but also to quantify the movement of contamination in the environment. One or more key contaminants must be selected as indicators, based on their persistence and mobility in the environment and the degree of hazard.

Aquifer parameters must be identified so that the rate and direction of flow can be determined. The data are needed both for the development and evaluation of remedial alternatives in the feasibility study and the subsequent engineering design. Effective data collection during the remedial investigation will minimize the need for additional field work during the design phase.

It is essential that the rate and direction of groundwater flow be determined in the investigation. In some cases, this is a relatively simple procedure using the effective porosity, hydraulic gradient and permeability of the contaminated aquifer and Darcy's equation to calculate groundwater velocity.

At one site, the contaminated flow was confined by a subsurface bedrock valley; therefore, the direction was known and the calculated velocity allowed a good estimate of when contamination would reach down-gradient wells. In more complex settings, computer modeling is required to determine the movement of area-wide groundwater plumes. One such site has a series of four aquifers beneath a concentrated source of contamination. Computer modeling was used to determine the rates and directions of plume movements and to assess the impact of alternatives to control migration.

The remedial investigation must also identify the impacts of plume movement on actual or potential receptors. This requires a survey of the human and environmental receptors so that potential for exposure to contamination can be identified. It also requires an estimate of the contaminant level that may reach affected receptors. However, the numerous variables in the concentration, such as dilution and attenuation of contaminants during migration, will generally make a quantitative analysis too expensive and inaccurate to determine the actual risk to receptors. Nevertheless, it is usually possible to make a qualitative estimate of exposure. In the case of potential human exposure, this evaluation should focus on the probability that potential receptors will be exposed to contaminants at levels above existing USEPA standards, criteria or other guidelines accepted as appropriate for the situation.

Accuracy of Data

The remedial investigation must include data of sufficient quality and quantity to allow engineers to develop and evaluate alternatives. Since cost is an important factor in selecting a remedial action, it is important that the cost of all alternatives be estimated to a level that will give the decision-maker a realistic cost comparison. Moreover, the data must be of adequate quality to allow cost estimates with a + 50% and − 30% accuracy.

The engineer who designs the sampling program must consider the data needed to evaluate possible remedial alternatives and the impact data collection has on cost estimation of those alternatives. The accuracy of costs will depend on several factors, including:
- Accuracy of analytical data
- Estimate of waste quantities
- Estimate of waste strength and characteristics
- Accuracy of assigning costs

Each of these factors (and possibly others) contributes to variations in the costing of alternatives.

Each site should be reviewed to identify the factors having the greatest impact on costs. This determination requires an assessment of potential alternatives that may be evaluated in the feasibility study to identify the data needed to adequately cost out the alternative.

An adequate remedial investigation should identify all potential alternatives early in the project and determine the necessary data needed to evaluate and cost those alternatives in the feasibility study. For example, the quantity and type of wastes in buried drums can significantly affect treatment or disposal costs. Therefore, the sampling plan will include excavation of test pits to sample a representative number of drums. The quantity and condition of the drums and the volume of waste types should be estimated so that an excavation and off-site disposal alternative can be evaluated.

Summary of Investigation Data

A remedial investigation will typically generate a large amount of data on various contaminants, locations and media polluted. This information must be summarized to show the concentrations and distribution of key contaminants for each medium investigated. An assessment of the actual or potential for human and environmental exposure will then be made to determine if the uncontrolled waste site represents a significant threat to the public or environment.

This exposure assessment should include a summary of the significant contaminants for each medium and their characteristics regarding movement in the environment, known or suspected health effects, actual or potential pathways of migration and actual or potential receptors. For groundwater contaminations, the exposure potential should be compared to available USEPA standards, criteria or other accepted guidelines. The exposure assessment is a key analysis that will be used to either approve or eliminate the "no-action" alternative in the feasibility study.

FEASIBILITY STUDY

The NCP describes the overall process for selecting a cost-effective remedial action. There are four steps in the process:
• Development of remedial alternatives
• Screening out of infeasible alternatives
• A detailed evaluation of the remaining alternatives
• The selection of a remedial action

The feasibility study converts the data on environmental contamination collected in the remedial investigation into a series of engineering solutions to the specific problem. Alternatives should be developed for a range of technologies and cleanup objectives, using acceptable standards, criteria and guidelines to establish baseline requirements. In the interest of cost and time, the feasibility study should fully evaluate only a limited number of alternatives. This section discusses several technical considerations and requirements that have emerged from the USEPA's review of recent RI/FS projects.

Development of Remedial Alternatives

It is essential that the feasibility study develop alternatives over a sufficient range of technologies and cleanup objectives to allow the decision-maker to make an effective choice. Many completed feasibility studies have not fully evaluated the appropriate alternatives, thus causing delays in selecting a remedial action while additional alternatives were evaluated.

As with remedial investigations, the feasibility study will usually focus on alternatives that control the source of the migration of contamination. For a typical source control measure, the following alternatives should be evaluated:
• Excavation of wastes and off-site treatment and/or disposal
• Excavation of wastes and on-site treatment and/or disposal
• In-place containment
• No-action

The excavation alternatives should usually consider several disposal technologies. Off-site disposal must be at a facility that complies with the requirements of RCRA and current USEPA policies. When kpossible, alternative technologies that achieve the destruction of wastes (e.g., incineration) should also be considered. The additional costs to destroy wastes, rather than merely dispose of wastes that would have the potential for future migration into the environment, can often be justified by the increased reliability.

On-site disposal alternatives must comply with the technical requirements of the RCRA regulations at 40 *CFR* Part 264. This will typically mean that a landfill in compliance with Part 264 Subpart N should be fully evaluated.

In-place containment alternatives that prevent or minimize the migration of contamination and the threat to public health and the environment must be evaluated. This may include a range of technologies such as capping, slurry walls, fixation and stabilization of wastes in place. Alternatives developed for on-site or in-place containment should also consider technologies that achieve the destruction or treatment of wastes.

Alternatives developed for contaminants that have migrated from the source must be capable of preventing or mitigating adverse public health and environmental impacts resulting from migration of the contamination in the environment. Contaminated groundwater is the major off-site problem. Typical alternatives that will be evaluated include:
• Extraction and treatment to reduce or remove contamination
• Barriers or gradient control to prevent further spread of contamination
• Provision of alternative water supply
• No-action

The feasibility study should always evaluate a groundwater treatment alternative that complies with RCRA regulations of Part 264 Subpart F. This regulation requires extraction and treatment until the groundwater concentration reaches either background levels or maximum permissible concentration limits. In some situations, alternatives that contain the spread of contamination, rather than removing it, must be evaluated. This step will be appropriate when the contamination has already spread over a large area or the source cannot be located or contained.

Two key considerations will be: (1) the duration of groundwater control measures and (2) the level of treatment required. The duration must be estimated to allow the calculation of present worth cost. The level of treatment should be appropriate for the intended use. Little or no treatment may be required if the water is discharged to a wastewater treatment plant. However, if water will be used for human consumption, applicable public health standards or criteria should be used.

Screen Out Infeasible Alternatives

During the screening step, alternatives may be eliminated from further consideration for several reasons:
• Clearly inadequate protection of public health or the environment (for example, the alternative does not prevent migration of contaminants)
• Comparatively high cost in relation to the protection and cost of other alternatives
• Significant adverse impacts of the remedy (for example, excavation of highly volatile, toxic wastes may have potential adverse impacts that cannot be mitigated)

As part of the screening process, requirements of other environmental acts should be assessed and the objectives of the remedial action defined for each medium threatened.

Remedial alternatives should prevent or minimize both present and future identified problems. Residual contaminants in the soil or groundwater should be removed or contained below standard levels or at a concentration that will not pose a threat.

Two to six alternatives generally remain after screening and are examined in detail as part of the cost-effective analysis. These will include the no-action and, for source contamination, construction of an on-site landfill in compliance with RCRA.

Detailed Evaluation

A detailed evaluation of the remaining alternatives is conducted to evaluate their cost-effectiveness in addressing technical, environmental and public health concerns. Environmental and public health considerations can often be readily evaluated in the context of compliance with appropriate standards, criteria or guidance. Hence, these factors are not discussed in detail here. It is the technical considerations which are often critical in selecting the alternative to be used.

Table 1
Typical Remedy Selection Factors

Cost
• Capital Cost
• Annual Costs
• Present Worth Cost

Technical Considerations
• Site Characterization
• Reliability
• Safety
• Operation and Maintenance Requirements
• Implementability

Environmental Considerations
• Adverse Effects
• Beneficial Effects
• Mitigation Measures

Public Health Considerations
• Populations Exposed
• Route of Exposure
• Type of Hazardous Substance
• Level of Exposures

Public Concerns
• Public Acceptability

Table 2
Cost-Effectiveness Summary

Alternative	Cost ($1,000) Capital	Cost ($1,000) Present Worth	Public Health Considerations	Environmental Considerations	Technical Considerations	Public Comment	Other
1. No Action	---	---	Unacceptable exposure to PAH if summer or fire demand requires use of contaminated well. Continued water shortages.	Continued migration of contaminated groundwater; leading to contamination of Town Y's water supply.	---	High resistance	
2. Hookup to City X	$250	$8,102	Reduces public health threat to less than 10^{-6}.	Continued migration of contaminated groundwater; leading to contamination of Town Y's water supply.	Relies on simple technology. No treatment is required.	Acceptable.	Has significantly higher O&M and present worth cost.
3. Drill Deeper Wells	$1,870	$2,916	Reduces public health threat to less than 10^{-6}.	Continued migration of contaminated groundwater leading to contamination of Town Y's water supply. Depletes limited water resource in deeper aquifer.	Relies on proven construction technology.	Acceptable to Town Z Park, but not to Town Y or Town A.	Has second highest present worth cost.
4. Aquifer Treatment A. Ozone	$374	$1,618	At 2000 ng/l of PAH, removes taste and odor, but results in 10^{-5} to 10^{-6} risk.	Blocks migration and allows additional wells to be opened.	Not used on wide scale. Less responsibe to slug loading than GAC. Would be expensive to retrofit if treatment goals change. Certainty that target levels will be consistently met is low due to operational inflexibility.	Acceptable.	Present worth is less than GAC at higher risk level but more at lower recommment goals.
	$459	$2,109	At 1000 ng/l of PAH, results in 10^{-5} to 10^{-6} risk.				
	$709	$2,434	At 280 ng/l of PAH, results in 10^{-6} or less risk.				
B. Granular Activated Carbon	$633	$2,150	At 2000 ng/l of PAH, removes taste and odor but results in 10^{-5} to 10^{-6} risk.	Blocks migration and allows additional wells to be opened.	Considered best available technology. Dependable over a wide range of operating conditions. Responds well to slug loading Likely to consistently meet risk target.	Acceptable.	Present worth is less than other technologies a recommended treatment level.
	$633	$2,263	At 1000 ng/l of PAH, results in 10^{-5} to 10^{-6} risk.				
	$633	$2,405*	At 280 ng/l of PAH, results in 10^{-6} or less risk.**				

* Recommended Alternative

** 280 ng/l is the operational performance target for the GAC treatment system at this site. The carcinogenic PAH will be reduced to a level less than or equal to 2.8 ng/l as a result of the operational performance target. This will assure that the health risk to the population is less than or equal to a 10^{-6} health risk.

Siting considerations, system reliability and effectiveness are key technical factors.

Site characterization: On-site containment may not be acceptable if the hazardous wastes are in a poor location and the containment structure cannot be designed to compensate for these shortcomings of the site. Important locational criteria include:

■Site stability
- Flood prone areas: sites within the 100 or 500 yr floodplain. Flood proofing could alleviate this threat; however, hazardous waste generally should not be contained in wetland areas.
- Seismic zones: disposal facilities could be damaged by ground shaking or associated ground failure or subsidence; ground motion could result in differential settling and could also cause sediments to liquify, settle or slide.
- Landslide areas: a landslide can impact a disposal facility by carrying waste materials downslope, by exposing waste materials or by covering run-on/run-off controls.
- Subsidence-prone areas: over a period of years, long term faulting and surface deformation can occur as a result of subsidence; i.e., one Superfund site in Texas may eventually sink below sea level.
- High groundwater that moves rapidly and thereby may threaten current or future use of the groundwater.

■Ability to monitor and take future corrective action. On-site containment may not be appropriate if the underlying stratigraphy is complex. (Such as areas with Karst geology or fractured bedrock.) A groundwater plume would be difficult or impossible to monitor, and corrective action would be difficult to accomplish.

Reliability: The reliability of a remedy can be evaluated in terms of the complexity of operation and maintenance and the demonstrated performance of the technology involved. Technologies requiring labor intensive or complex activities are generally less reliable than systems with straightforward activities. But the most important aspect of reliability is the ability of the remedy to meet its long term performance goals. The method and result of failure must be evaluated as part of the reliability analysis.

Implementability: Remedies that can be constructed in a short time and rely on demonstrated construction techniques are favored. Also, remedies which do not threaten workers, the environment or the surrounding community during construction are favored.

SELECTION OF A REMEDY

All remedial actions undertaken under the auspices of CERCLA must be selected by the USEPA. All alternatives fully evaluated in the feasibility study will be presented to the decision-maker. A list of screened out alternatives will also be presented. The feasibility study will not normally include a recommended alternative, since public comments on the alternatives must be considered before selecting a remedy. Alternatives proposed by public or private parties that were not evaluated in the feasibility study will also be presented.

A number of factors must be evaluated before a remedial action can be approved. These include:
•Cost
•Technical considerations
•Environmental considerations
•Public health considerations
•Public concerns

Typical components for each category are shown in Table 1.

The NCP requires that the USEPA select the "lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare or the environment." Full technical compliance with all applicable and relevant USEPA standards is the Agency's goal. However, limited exemptions may be appropriate. For example, the USEPA might grant exemptions on a site specific basis if the alternative that would be in technical compliance has excessive costs or if site conditions make compliance infeasible. Therefore, alternatives that may not comply with USEPA requirements but which provide effective protection of public health, welfare and the environment should be presented.

In some situations, use of USEPA advisories may result in a range of alternatives. For example, treating contaminated water supplies to achieve a range of carcinogenic risk levels may result in similar alternatives with varying costs. These will be presented to the decision maker.

The USEPA has found a trade-off matrix useful to summarize the alternatives and their relative advantages and disadvantages. A sample matrix is shown in Table 2. The information summarized in this matrix must be fully explained in the feasibility study. In some cases, all evaluation considerations will point to a single alternative. However, several alternatives will usually have competing advantages and disadvantages, making a decision more difficult.

If the least cost alternative fully complies with USEPA requirements, it will generally be selected. However, the USEPA also prefers alternatives that achieve treatment or destruction rather than storage or disposal of wastes. (This consideration applies to both on-site actions and off-site facilities that will receive wastes removed from a Superfund site.) In all cases, the USEPA must evaluate and document the selection process to ensure that its decision with respect to the various sites is generally consistent, but also reflects the specific conditions of each site.

GUIDANCE FOR THE CONDUCT OF REMEDIAL INVESTIGATIONS/FEASIBILITY STUDIES UNDER SUPERFUND

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INTRODUCTION

In this paper, the authors discuss the framework for the design and implementation of an effective remedial investigation/feasibility study (RI/FS) project and focus on the most important aspects of this framework. Although individual site conditions may vary, the general framework developed here is flexible enough to accommodate these considerations and provide effective remedial planning at any site. The framework described follows the National Contingency Plan (NCP) (40 *CFR* Part 300).

The remedial investigation provides an initial assessment of the site conditions, identifies data needs, defines the physical and chemical conditions of the site that affect the implementation of remedial measures and identifies current or potential threats posed by the site. The RI emphasizes the collection and analysis of data rather than the evaluation of the implications of the data. Results of RI (Fig. 1) efforts produce a data base of source, environmental and impact characteristics sufficient to evaluate the need for, appropriateness and/or effectiveness of alternative remedial actions.

During the FS, the information gathered during the RI, and any other relevant data, are analyzed and evaluated to identify the strengths and weaknesses of various remedial alternatives. The FS (Fig. 2) addresses five major characteristics of remedial alternatives: (1) technical, (2) public health, (3) environmental, (4) institutional (compliance with legal requirements and policies) and (5) cost.

Even though the RI and the FS emphasize different aspects of the overall response, the two efforts are interdependent. The relationship of the RI to the FS in terms of timing and findings is shown in Figure 3. Interim reports that document data and findings generally are not formally required of the RI/FS effort. The RI may be conducted in steps contributing to alternatives development and analysis in the FS. These steps are discussed below.

INITIAL ACTIVITIES

An important first step in an effective remedial investigation is the review of existing data. The review should go beyond simply describing the current situation; it should also identify the scope and procedures of subsequent investigations. These two important efforts are shown as Tasks 1 and 2 of the remedial investigation in Figure 3.

Initial development of a background report detailing the nature and extent of the problem and outlining the purpose and need for further investigations and remedial actions is critical to effective remedial response. This initial assessment often is used to develop response objectives, determine the particular requirements for further investigations and serve as the basis for enforcement activities. This aspect will be discussed in more detail under Problem Definition and Project Scope.
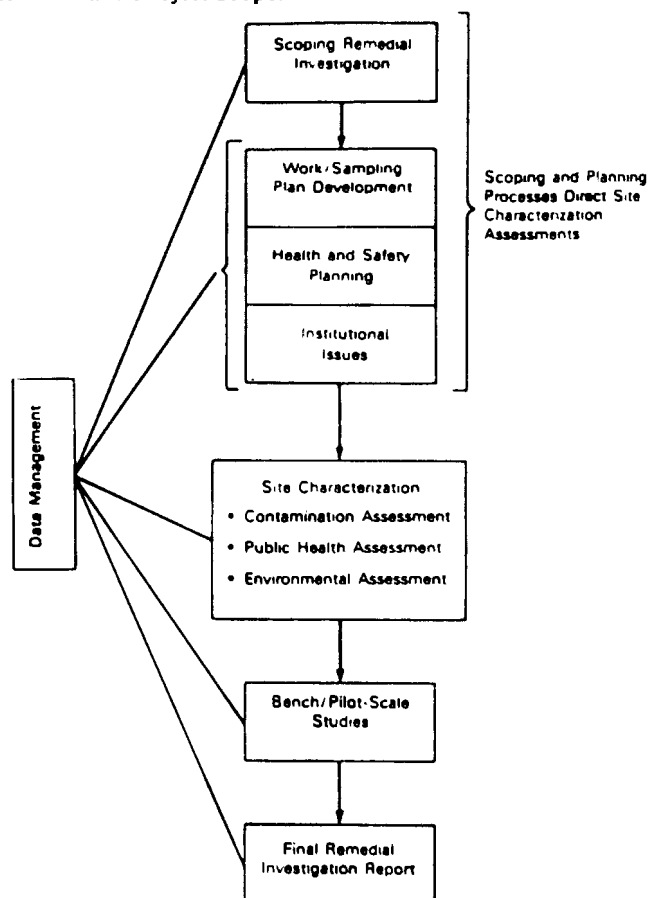
Figure 1
Remedial Investigation Process
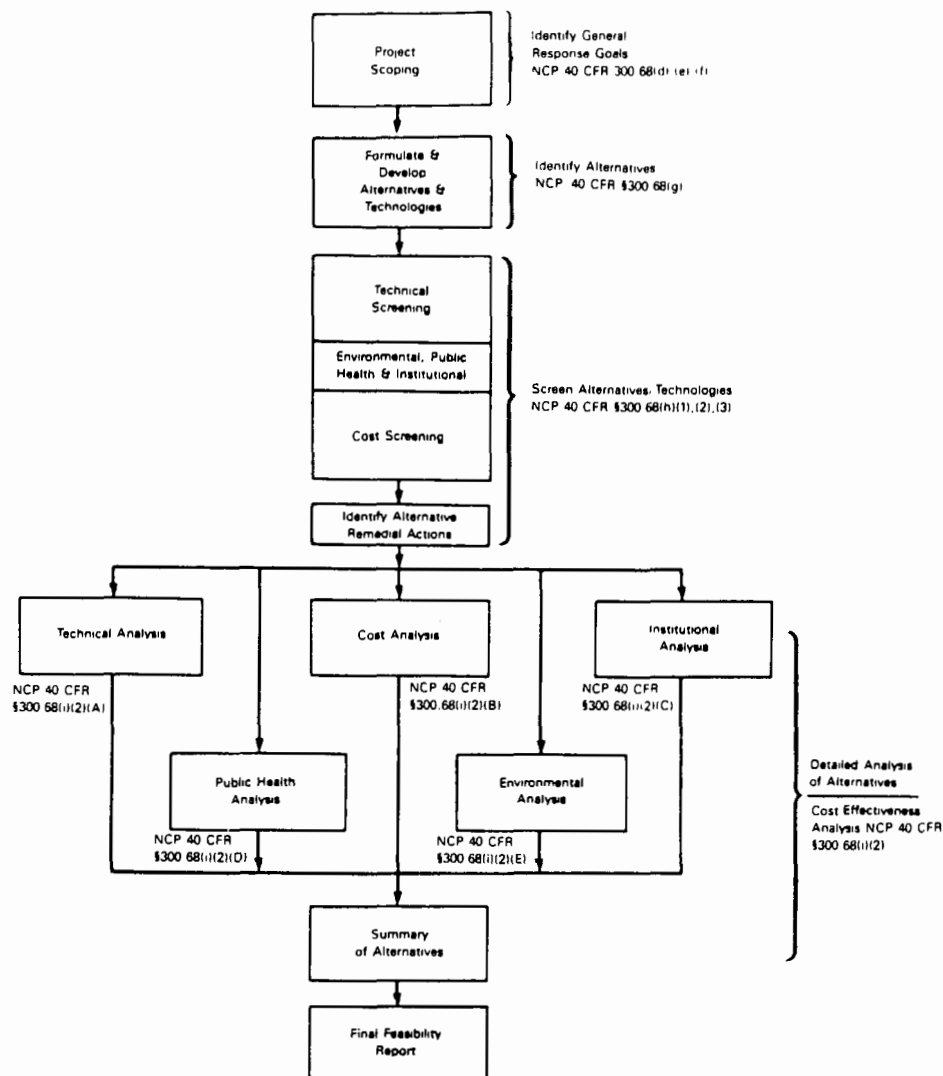
Figure 2
Feasibility Study Process

Typical response objectives address contaminated aquifers and/or water supplies, remedy surface water contamination, remove direct contact hazard and other similar concerns. Once response objectives have been determined, the scope of the remedial investigation is determined. The work to be performed under the remedial investigation should consider the quantity and quality of existing data, data needed to evaluate likely remedies and data needed to determine present and potential health and environmental threats. This important use of existing data is often overlooked in developing remedial action plans.

The initial assessment may also establish the basis for subsequent enforcement activities. An important part of the initial assessment is a review of existing data on the levels of contamination in the surrounding groundwaters, surface waters, air and drinking waters. These data are compared to relevant public health and environmental standards and criteria to establish a basis for requiring private-party remedial actions. As exposure and effects data are evaluated during the RI/FS process, the initial report forms the basis for a public health assessment.

Often, initial assessments involve a site visit to confirm data regarding site access, topography, exposed populations and other information. The site visits and any data collection are performed according to general safety and sampling plans. Once the site visit has been performed, detailed remedial investigations and management plans are developed. These detailed, site-specific plans can

be modifications of the more general plans. These plans, under the site-specific work plan, include: the site safety plan, the quality assurance/quality control (QA/QC) plan, the chain-of-custody plan, the sampling plan, the community relations plan and the site/data management plan.

PROBLEM DEFINITION AND PROJECT SCOPE

Initial feasibility study activities build upon the initial data developed in the remedial investigation. The feasibility study efforts, at this point, include a description of the proposed response and the development of preliminary remedial technologies. These activities are shown as Tasks 8 and 9 in Figure 3.

The initial description of the site characteristics from the RI allows a preliminary identification of response actions that could be considered as likely remedial alternatives. These general response actions do not necessarily identify specific technologies but do identify generic activities for site remediation. Examples of such generic activities include:
•Containment
•Removal
•Groundwater pumping and treatment
•Alternative water supplies
•Ground or surface water diversion
•In situ treatment

These general activities often comprise specific technologies that can be readily evaluated for suitability at the specific site. When this can be done, specific data that must be gathered during the remedial investigation can be identified. If the specific technologies cannot be identified at this stage, an effort should still be made to identify specific data requirements.

The description of the proposed response details general response objectives in terms of media affected, populations concerned, pathways of exposure to be remedied and likely technologies to be employed. A clear statement of response objectives should be made to ensure that a comprehensive response is planned. Further, a detailed statement of response objectives ensures the identification of all data necessary to evaluate alternative responses. Thus, the compilation of existing data, the identification of data needs through a detailed statement of response objectives and an initial evaluation of likely remedial technologies provide the information needed to determine the scope of an effective RI/FS effort. An interim report should be written at this point in the RI/FS to provide interested parties a chance to review progress.

SITE INVESTIGATION AND ALTERNATIVES ANALYSIS

Site investigation activities in the RI are focused on characterizing the site with regard to public health and the environment, establishing baseline environmental and health conditions and obtaining data for use in the FS. Simultaneously with the site investigation, FS activities are initiated using data made available from the RI to analyze and to pinpoint applicable remedial alternatives through a series of screening and analysis processes. These activities are shown in Tasks 3 and 4 of the RI and Tasks 10, 11 and 12 of the FS in Figure 3. The objective of integrating the RI and FS activities at this stage of the site response is to efficiently use the resources committed to site characterization efforts in the quantification of data to screen and evaluate remedial alternatives.

Quantitative data obtained during the site investigation should include general source, pathway and receptor information used to screen proposed remedial alternatives. The data collected during this effort should include:

•*Environmental Setting.* Data to define the site and facility characteristics should be collected commensurate with the preliminary remedial technology options of interest. Environmental data should describe the geography and layout of the site and surrounding areas; topography; waste source locations, waste type; geotechnical engineering considerations; normal and unusual meteorological conditions; surface drainage patterns; geologic features; groundwater occurrence, flow direction and rate; and soil type and chemistry.

•*Hazardous Substances.* Analytical data should be collected to completely characterize the wastes including type; quantity; physical form; degree of contamination; disposition (containment or nature of deposits); and facility characteristics affecting release (e.g., site security, engineered barriers, etc.). These data may also be required to support decisions on interim remedial measures.
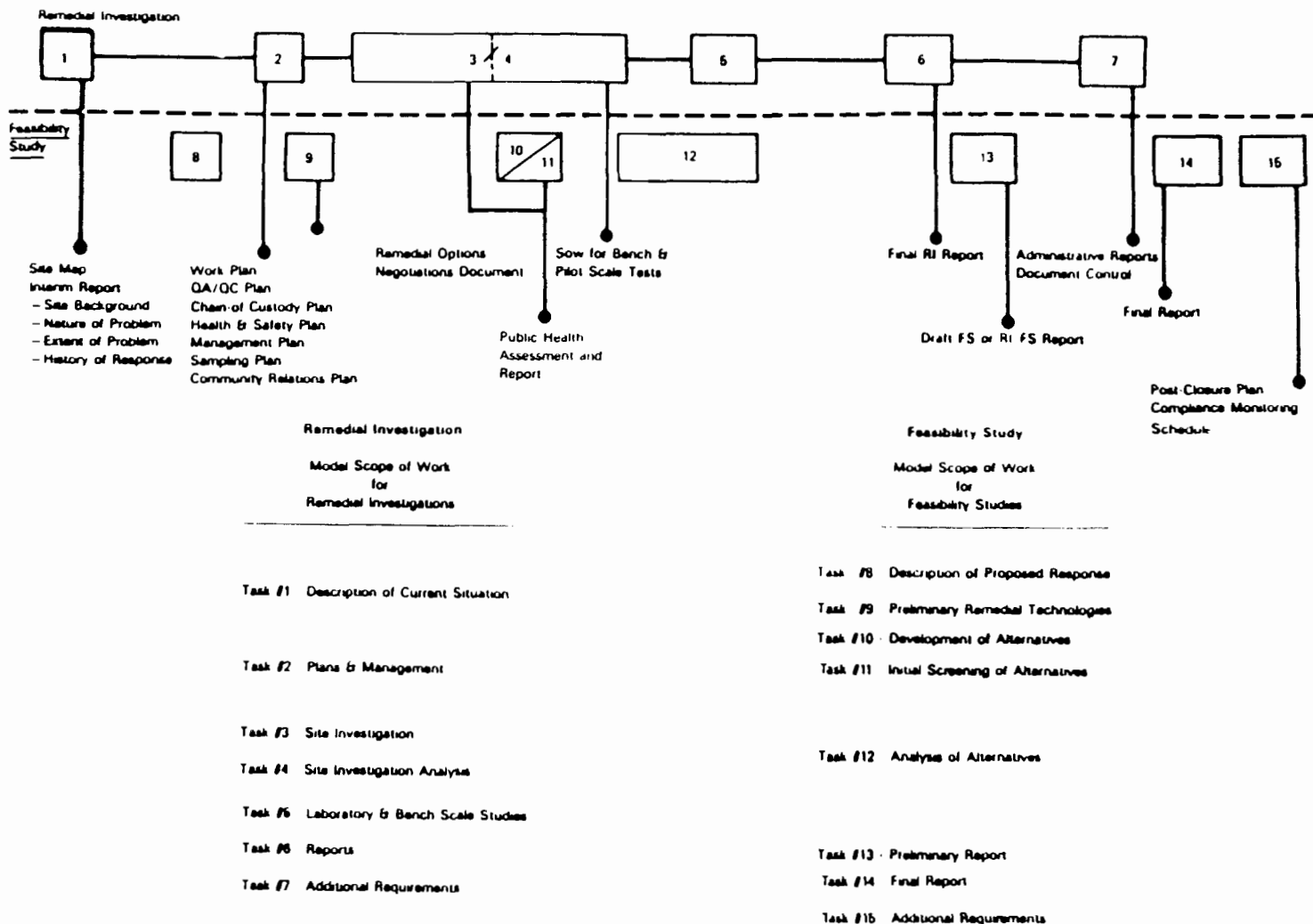
Figure 3
RF/FS Process

•*Environmental Concentrations.* Analytical data on air, soils, surface water and groundwater contamination in the vicinity of a site should be collected. These data should be sufficient to define the extent, origin, direction and rate of movement of contaminant plumes. Sufficient background data should be collected to allow an assessment of hazards posed by the site in relation to the surrounding environment. Data should include time and location of sampling, media sampled, concentrations found, conditions during sampling and the identities of individuals performing the sampling and analysis.

•*Potential Impact on Receptors.* Data describing the human populations and environmental systems that are susceptible to contaminant exposure via the transport pathways from a site should be collected to assess present or potential exposures. Chemical analysis of biological samples may be needed. Data on observable effects in ecosystems may also be obtained.

•*Remedial Action Effectiveness.* Data relevant to the feasibility and effectiveness of proposed remedial actions should be collected. Because of the diversity of potential alternatives, specific investigations of this nature may be delayed until the conclusion of relevant portions of the feasibility study.

As a result of the site characterization activities, several types of assessments can be performed. Three types of typical assessments are: (1) a contamination assessment determining how the contaminants are distributed and moving; (2) a public health assessment determining the human health implications and establishes baseline conditions for potential litigative action; and (3) an environmental assessment determining environmental implications of the site. In achieving the goals of the site investigation and associated assessments, several types of technical investigations are required. These investigations may include source characteristics, geologic and pedological conditions, groundwater characteristics, surface water transport mechanisms, atmospheric conditions, identification of contaminants of concern, human health effects and biological and ecological effects.

A thorough analysis and summary of all site investigations and their results should be prepared to ensure that the investigation data are sufficient in quality and quantity to support the feasibility study. The data from all site investigations should be organized and presented logically to clearly show the relationships between site investigations for each medium.

During and immediately following the site investigation effort, a feasibility study is directed at developing a limited number of alternatives for source control or off-site remedial actions. These alternatives are developed in response to the objectives of the site remediation efforts and the results of the RI.

A critical step is the establishment of site-specific objectives for the response. These objectives will be based on public health and environmental concerns, the description of the current situation (from Task 1), information gathered during the remedial investigation, Section 300.68 of the National Contingency Plan (NCP), applicable USEPA RI/FS guidance and the requirements of any other applicable USEPA, Federal and State environmental standards, guidance and advisories as defined under the USEPA's CERCLA compliance policy. Objectives for source control measures should be developed to prevent or significantly minimize migration of contamination from the site. Objectives for off-site measures should prevent or minimize impacts of contamination that has migrated from the site. Preliminary cleanup objectives should be developed in consultation with the USEPA and the State.

Once response objectives are established, a series of remedial alternatives are identified. These alternatives incorporate remedial technologies (from Task 9), response objectives and other appropriate considerations into a comprehensive, site-specific approach. There may be overlap among the alternatives developed, and additional data may be required to fully develop the alternatives. Alternatives should be developed in close consultation with the USEPA and the State; the rationale for excluding technologies earlier considered applicable should be documented. During this part of the remedial response, the RI and FS activities need to be well coordinated; information should be flowing freely from one to the other.

After a series of remedial alternatives has been developed, it is often necessary to reduce the remedial action options to a manageable number. Initial screening of alternatives is performed using three broad considerations as performance factors: public health, environment and costs. In detail these factors include:

•*Public Health and Environmental Protection.* Only those alternatives satisfying the response objectives and contributing substantially to the protection of public health, welfare or the environment should be considered further. Source control alternatives should achieve adequate control of source materials. Off-site alternatives should minimize or mitigate the threat of harm to public health, welfare or the environment.

•*Environmental Effects.* Alternatives posing significant adverse environmental effects should be excluded.

•*Cost.* An alternative whose cost far exceeds that of other alternatives will usually be eliminated unless significant benefits will also be realized. Total costs will include the costs for implementing, operating and maintaining the alternatives.

At, or near the conclusion of, the RI site characterization activities, there should be sufficient data to complete a detailed evaluation of these alternatives. Alternative evaluation efforts in the FS should include:
•Detailed development of the alternatives
•Environmental analysis
•Public Health analysis
•Institutional analysis
•Cost analysis

Alternatives should be evaluated using technical environmental and economic criteria. At a minimum, the following areas should be used to evaluate alternatives:
•Health information
•Environmental effects
•Technical aspects of the remedial alternatives
•Present worth of total costs
•Information on technical and environmental standards and advisories
•Information on community effects
•Other factors

The results of this evaluation and any material documenting factors directing the evaluation efforts are passed on for incorporation in the preliminary report.

REFINEMENT OF TECHNOLOGY EVALUATION

Bench and pilot scale studies may be necessary to obtain sufficient data for the selection and implementation of remedial action alternatives. As shown in Figure 3, bench and pilot scale studies are part of the RI task sequence (i.e., Task 5) and generally should be conducted concurrently with the later stages of the analysis of alternatives in the FS (i.e., Task 12). The interaction between these two tasks is important. The analysis of alternatives may require the bench and pilot scale information to determine the feasibility of a given technology since there may be a lack of long-term performance information about remedial action technologies and site and waste heterogeneities.

Bench scale studies differ from pilot scale studies in purpose, size and application. Bench scale studies are much smaller in scale, cost, time and waste volume. Their purpose is to determine application feasibility over the expected range of conditions. Bench scale studies are flexible; a wide range of variables can be evaluated when determining the performance limitations and capabilities of a technology.

Pilot scale studies, on the other hand, are used to guide the selection of one alternative from several (when this cannot be done appropriately at the bench scale) and to define the design, operating criteria and specific features of an alternative likely to be selected. Pilot scale studies can be used to determine the stability of a process or material (e.g., compatibility tests) in an application

Table 1
Examples of Bench and Pilot Scale Testing Programs

Remedial Technology	Example Testing Programs
A. Air Pollution and Gas Migration Control 1. Capping 2. Dust Control 3. Vapor Collection and Treatment (carbon adsorption)	Bench. Soil density and bearing capacity vs. moisture content curves for proposed capping materials. Pilot: In-place soil densities, determination of gas withdrawal rates to control releases.
B. Surface Water Controls 1. Capping 2. Grading 3. Revegetation 4. Diversion and Collection	Bench: Horticultural testing to select grass species and soil conditioning for vegetative cover. Pilot: In-place testing of geotextiles for control of erosion in grassed diversion ditches.
C. Leachate and Groundwater Controls 1. Containment barriers (slurry walls, grout curtains, etc.) 2. Groundwater pumping (well points, suction wells etc.) 3. Subsurface collection drains 4. Permeable treatment beds (limestone, AC) 5. Capping	Bench: Determination of basirity and headloss vs grain size of limestone materials for a treatment bed. Determination of chemical compatibility of a compacted clay with a leachate stream. Pilot: In-place testing of a soil type and grain size specification and tile drain configuration for a subsurface collection drain.

D. Direct Waste Control
1. Incineration
2. Solidification
3. Biological
  Activated sludge
  Faculative lagoons
  Trickling filters
4. Chemical
  Oxidation/Reduction
  Precipitation
  Neutralization
  Ion exchange resins
5. Physical
  Carbon adsorption
  Flocculation, Precipitation, Sedimentation
  Membrane processes
  Dissolved Air Flotation
  Air Stripping
  Wet Air Oxidation
6. In Situ Treatment
  Microbial Degradation
  Neutralization/Detoxification
  Precipitation
  Nitrification
7. Land Disposal (landfill, land application)
	Bench: Characterize chemical and heat content of hazardous waste mixes; Conduct chemical, physical and biological treatability studies to define, e.g., rate constants, minimal-maximal loading rates and retention times, optimal pH and temperature, sludge generation rates and characteristics, and oxygen transfer characteristics; chemical type and dose rates solids flux rate vs solids concentration in sludge thickening systems; air/volume ratios for stripping towers.
	Pilot: Conduct test burns to determine retention time, combustion chamber, and afterburner temperatures, and fuel make-up requirements for the incineration of a waste. Conduct endurance/performance tests on membranes in reverse osmosis units for groundwater treatment. Conduct in situ microbial degradation testing of nutrient dose and aeration rates to support in-place degradation of contaminants in a plume from an underground leak. Evaluate in-place mixing procedures for the solidification of a sludge in a lagoon.

E. Soil and Sediment Containment And Removal 1. Excavation 2. Dredging 3. Grading 4. Capping 5. Revegetation	Bench: Determine soil adsorptive (cation exchange capacity) properties and chemical composition Pilot: Conduct geophysical survey to map containment plume depth and extent. Conduct magnetometer survey to locate buried metallic objects.

and are aimed at delineation of specific design and operating criteria.

The diversity of activities that may be required in the selection and application of a remedial technology is shown in Table 1. The examples of bench and pilot scale studies presented illustrate the diversity of disciplines and sciences required to define application conditions for the technologies.

DRAFT RI/FS REPORTS

The final RI report is shown as Task 6 in Figure 3. This report should include the results of Tasks 1 through 5 and should include additional information in appendices. A recommended format has been established; it is structured: (1) to enable the reader to easily cross-reference data; (2) to ensure that all major issues are adequately addressed; (3) to promote high quality and consistency in RI studies; and (4) most importantly, to ensure adequate documentation and completeness of data entering into the decision-making process.

The Public Health Assessment Report is prepared as needed for enforcement cases. This report is prepared earlier in the RI study as an evaluation of exposure and risk to human health and the environment, drawing on data and analysis from Task 4, the Site Investigation Analysis, as shown in Figure 3.

The draft final FS Report (or combined RI/FS Report) is shown as Task 13 in Figure 3. In this report, the engineers should summarize the results of Tasks 8 through 13 and should include any supplemental information in appendices. Again, a recommended format has been established to permit the evaluation of feasibility studies on a common basis and shorten the lead time required for the selection and implementation of the cost-effective remedial action strategy.

A draft FS report provides a decisionmaker with important information for choosing the remedy providing the best balance between cost and health protection, environmental protection and engineering reliability. A minimum of 21 days is also provided after completion of the feasibility study for the public to comment on the alternative analysis. Based on the public comment, revisions to some or all alternatives may be appropriate. A response of this summary is prepared in the final revision of the FS report to document public comments and to describe the actions taken regarding these comments.

ADDITIONAL REQUIREMENTS

Tasks 7 and 8 in Figure 3 indicate that additional requirements may be needed. These include items such as administrative reports, document control procedures, community relations support,

post-closure plans, compliance monitoring schedules and other situation-specific requirements.

CONCLUSIONS

An organized management approach to remedial investigations and feasibility studies should avoid many of the problems encountered in less well-planned studies and thus lead to successful cleanup. This paper has summarized detailed guidance that will be forthcoming from the USEPA.

The information in this paper is based on August, 1984, draft guidance for conducting remedial investigations and feasibility studies under CERCLA. The information is subject to change and does not necessarily reflect official USEPA guidance. The reader is advised to consult with the USEPA for revisions to the guidance.

CLEANUP OF RADIOACTIVE MILL TAILINGS FROM PROPERTIES IN MONTICELLO, UTAH

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INTRODUCTION

In conjunction with an early 1970s USEPA investigation of possible tailings misuse at a former U.S. Atomic Energy Commission (AEC) uranium millsite in Monticello, Utah, two sites were tentatively identified as being radioactively contaminated. The sites were an occupied residence on a 0.6-acre lot and a small downtown store, both built during the mid-1940s.

Studies carried out by the USEPA, the U.S. Department of Energy (USDOE) and the Utah State Health Department in the early 1980s revealed radon progeny and gamma radiation levels in the structures that were greatly in excess of generally accepted health criteria. Believing the radioactivity had originated from the AEC operation, USDOE carried out engineering assessments for both buildings can concluded that the source of the contamination was radioactive mill tailings incorporated into the adobe walls of the buildings and used as fill underneath or adjacent to them. However, a search of the build records revealed that the mill tailings had evidently been obtained from the vanadium processing facility which predated the AEC uranium plant. This meant that the USDOE, successor agency to the AEC, did not have authority to conduct any remedial activity, and this effectively suspended progress at the sites until USEPA action under the Superfund program was initiated in 1981. A "Superfund" cleanup was completed under authority of CERCLA during the summer of 1984, and the restored properties were reoccupied by their current owners.

History

The historical beginnings of uranium and vanadium processing in Monticello date back to the latter part of the 19th century, when carnotite, an ore containing uranium, radium and vanadium, was discovered in the Colorado Plateau area of southeastern Utah and southwestern Colorado. The extraction and processing of these materials followed cycles that were determined by markets for them and their availability from alternate sources. For example, exploration for and processing of carnotite reached a peak during the early 20th century when the Denver Radium Institute was producing radium for research and medicinal purposes. This market subsequently collapsed with the discovery of extensive, rich deposits of ore in what is now Zaire.[6]

Another peak in carnotite mining began in the late 1930s when the outbreak of war in Europe stimulated interest in assuring the availability of adequate domestic sources of canadium and other minerals. Vanadium is a non-radioactive metal used as a hardener in steel, and the federal government—through its depression-era agencies and authorities—played a major role in creating and con trolling the markets for it.

The Monticello mill processed vanadium as a part of the World War II production effort until 1944 when sufficient stockpiles were produced. The closure of the mill was only temporary, however. It was reopened in 1946 and used to produce uranium for the U.S. Government's World War II atomic weapons program (the Manhattan Project) and post-war Atomic Energy Commission projects. The mill continued to produce uranium for the defense effort until 1960, when it was closed and the buildings were dismantled. USDOE still controls the millsite under its Surplus Facilities Management Program. The one million tons of tailings in several stabilized piles are all that remain there. Although this mill is now history, mining and milling of uranium for nuclear power applications continues in southeastern Utah to this day.

At the time the two buildings were constructed in 1944-45, there was little or no appreciation for the potential health hazards of the radioactivity in the vanadium mill tailings. There were no controls on the use of these waste materials at that time except how they might best be stored at a minimum cost. In the 1960s and '70s, the USEPA and its predecessor agencies conducted field surveys that identified the presence and magnitude of the uranium mill tailings dispersal problem, primarily in the western United States. These studies played a major role in the passage of the Uranium Mill Tailings Radiation Control Act of 1978 (P.L. 95-604). This Act empowered the Nuclear Regulatory Commission to regulate present and future uranium milling operations according to standards set by the USEPA to prevent this problem from reoccurring in the future. In addition, it authorized the USDOE to clean up certain designated inactive uranium millsites to meet USEPA standards. With this Act, the Government recognized its obligation to remedy problems created by the production of uranium for the defense effort, but left unresolved the problems created by the production of similar wastes generated prior to the "Atomic Age." Where such problems exist—as in Monticello—the use of Superfund may be an alternative for resolution.

HEALTH IMPLICATIONS OF RADIATION EXPOSURE

The mill tailings used in the construction of the two buildings in Monticello contained up to 280 pCi/g* radium (Ra-226). Radium is one of a number of radioactive elements which comprise the daughter products of uranium (U-238). In fact, 13 different radioactive elements are formed in sequence as the uranium ultimately decays down to stable lead, as shown in Figure 1. Radioactive elements, or radionuclides, emit gamma rays and decay by the emission of alpha particles and beta particles. These three—alpha, beta and gamma radiations—are referred to as ionizing radiations

in order to distinguish them from less energetic particles or electromagnetic radiations such as microwaves and light or radio waves.

Alpha particles are physically identical to helium nuclei, containing two protons and two neutrons; they are the most ionizing but least penetrating of the common radiations. Outside the human body, they represent a negligible health threat as they cannot even penetrate the epidermal layer of the skin. If inhaled or ingested, however, alpha particles may become a significant human exposure problem.

Beta particles are, in reality, high-speed electrons originating in the nucleus of a decaying, unstable atom. They are less ionizing than alpha particles, but are more penetrating. The more energetic beta particles found in nature can penetrate up to a few centimeters of tissue and a few meters in air.

Gamma rays are not particles at all, but are highly energetic photons, similar to x-rays, which can easily penetrate several centimeters of tissue and are considered a hazard for radiation exposures both external as well as internal to the body. All three of these radiations are produced in the decay of either radium or its daughter products.

Of all the radionuclides in the uranium decay series, radium and its immediate daughters are the ones of greatest human health concern. Radium, with a half-life of 1,620 years, will remain at its present concentration in the environment for long periods compared to a human lifetime unless it is physically removed. Radium by itself, however, is not of such great concern as its decay products, viz., radon (Rn-222), polonium-218 (also called radium-A), lead-214 (called radium-B), bismuth-214 (called radium-C) and polonium-214. Radon is unique among this group because it is a noble gas that is inherently mobile at normal temperatures and pressures, while all the others are solids. This gaseous nature of radon is what makes a radium contamination problem so troublesome, for there is, thus, an inevitable, built-in, airborne dispersal mechanism contained in the radium decay chain.

Furthermore, the decay products of the radon have very short half-lives, making them very radioactive. When radium decays to radon, which has a half-life of about 4 days, the resulting gas has a good opportunity to diffuse out of the material in which the radium was contained and thence into the atmosphere before undergoing subsequent decays.

If the radon is contained within a volume and not allowed to disperse, the airborne concentration of the radon daughters can build up to levels that may represent a significant health threat if inhaled over an extended period of time. This is, in fact, what happened in some of the uranium mines before the problem was recognized and mine ventilation was required by law.

The health hazard posed in the short term by radiation from radium and its daughter products in concentrations usually found in the environment is normally not life-threatening, as the radium is almost never sufficiently concentrated to cause acute radiation syndrome or other prompt radiation effects. Rather, the hazard is generally considered to be a greater likelihood of cancer induction at some future time, with the probability of cancer directly proportional to radiation dose.

The human exposure from radium-bearing materials is twofold: first, the external exposure to gamma radiation from some of the radium decay products; and second, the internal exposure to the lungs because of the inhalation of the short-lived radon daughter products which emit alpha particles. Of these two, the second is by far the most significant, representing the largest radiation exposure normally received by the general public from any source.[3] The health effect of greatest concern, therefore, is lung cancer induction, and it has been estimated that between 2000 and 20,000 of the 120,000 annual lung cancer deaths in this country may be the result of exposure to radon daughter products.[1, 2, 4]

Standards for the regulation of gamma radiation exposure to radiation workers have been set by the Nuclear Regulatory Commission; allowable limits to the general public were issued by the

Federal Radiation Council, whose responsibilities subsequently transferred to the USEPA. The standards are expressed in terms of the maximum allowable dose per year in units of "rems"*. Radiation workers are allowed to receive up to 5 rems/yr (10 *CFR* 20), while individuals in the general public may receive up to ½ rem/yr*, exclusive of natural background radiation or any medical radiation exposure. For comparison purposes, natural background radiation in the Monticello, Utah area is estimated to be about 0.14 rem/yr. Based on measurements made in the two buildings addressed here, people living in the residential structure could receive up to 0.33 rem/yr based on an assumed occupancy 75% of the time. People working in the store could have received up to 0.2 rem/yr based upon an assumed average work time of 40 hr/week.

The standards for controlling exposure to the short-lived radon daughters are not as well defined as those for gamma radiation ex-
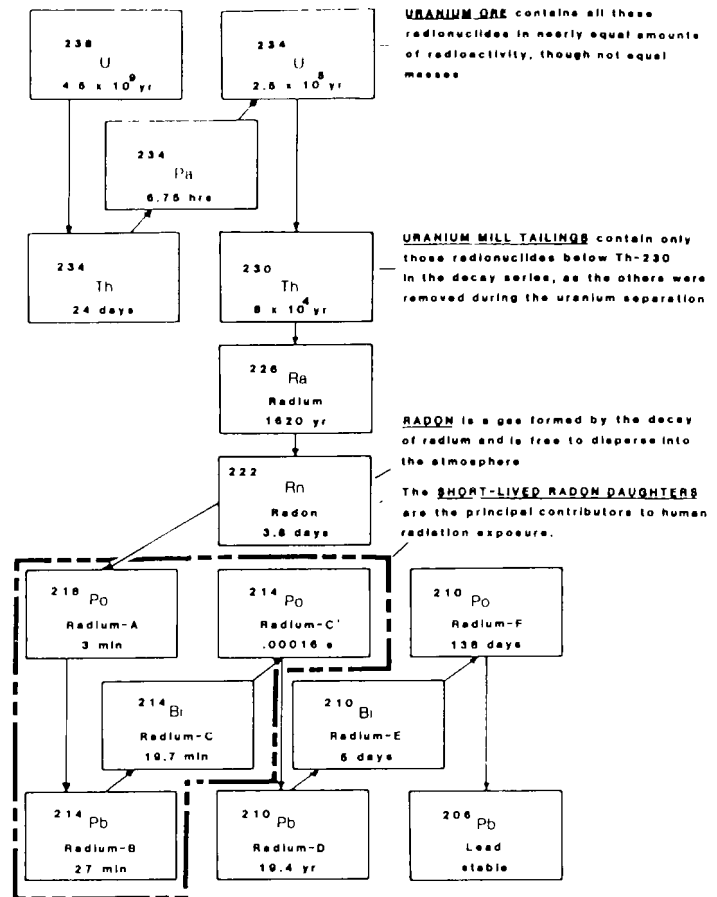
Figure 1
Uranium-Radium Decay Series

posure. The units are different as well, often being expressed as "working level-months" (WLM), where the working level† is a measure of the radon daughter concentration expressed as the potential alpha particle energy contained therein. A WLM is defined as the exposure an individual would receive in an atmosphere containing one (1) WL if he remained there for 170 hr, an average working month. The Mine Safety and Health Administration of the U.S. Department of Labor set a maximum limit of 4 WLM/year for persons working in uranium or other mines but did not address exposure limits for the general public. The USEPA has,

* pCi/g = picocuries of radium per gram of soil; a picocurie is a fractional portion of a curie, a unit of radioactivity equal to 3X10¹⁰ disintegrations per second.

* rem: The unit of dose equivalent, which is equal to the product of the absorbed radiation dose, the quality factor for different LET radiations, and any other modifying factors.

† Working level: a special unit of exposure to short-lived radon decay products in air; one Working Level equals 1.3 × 10⁵ MeV of potential alpha energy from any combination of radon daughters per liter of air.
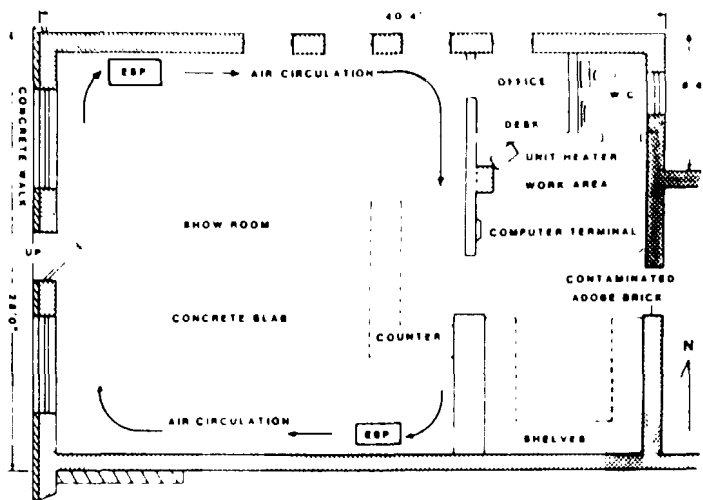
Figure 2
Floor Plan Showing Installation of Electrostatic Precipitators (ESPs) in Store
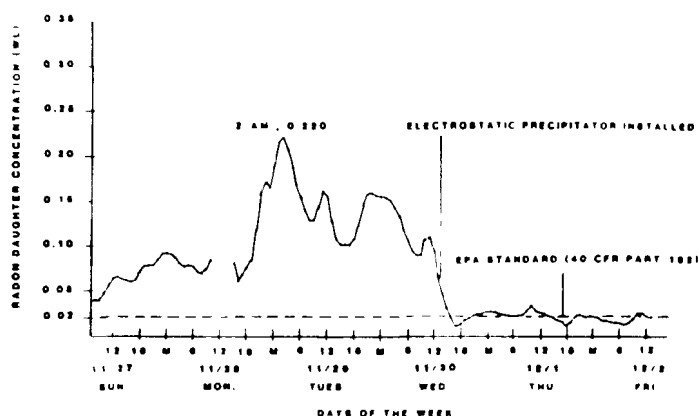
Figure 3
Radon Daughter Reduction Due to Electrostatic Precipitator

however, set radon daughter exposure standards for certain specific cases which are quite similar to the Monticello situation.

Under the Uranium Mill Tailings Radiation Control Act, the USEPA set standards for the cleanup of certain designated inactive uranium mill tailings sites and any nearby properties contaminated with tailings (40 *CFR* 192). According to these standards, the maximum radon daughter concentration (RDC) permitted in a habitable building contaminated with uranium mill tailings is 0.02 WL based on an annual average determination. For comparison, the authors estimate that the typical U.S. home has an average of 0.005 WL.

Before rehabilitation, the residential structure in Monticello had an average concentration estimated at 0.1 WL, five times the USEPA standard. The store was even higher with an estimated average concentration ranging between 0.2 and 0.3 WL; ten to fifteen times the USEPA standard. While the USEPA standards do not legally apply here, these standards were adopted as the minimum goals for the cleanup project because the situation was analogous to that contemplated in 40 *CFR* 192.

The standards found in 40 *CFR* 192 are useful in deciding when the gamma radiation exposure rate or the indoor radon daughter concentration is too high. The actual health risk from this exposure represents an important consideration in the standards setting process. The adverse health effect expected from excessive radiation exposure is an increase in the probability of cancer in the future. There are many studies involving both human and animal subjects which have been used to define the relationship between health effects and radiation dose. Most health effects, however, were

noted at much higher doses than found in this current situation, so extrapolation from higher to lower doses is necessary in order to predict the probability of future health effects. There is, of course, some uncertainty introduced by this extrapolation, but it must be recognized that what is being discussed is the statistical probability that an event will occur. Any such prediction has some uncertainty inherently associated with it when applied to specific individual radiation doses.

As mentioned earlier, the dominant risk posed by radioactive tailings is an increase in the probability of lung cancer from the inhalation of radon daughter products. According to USEPA studies, [3,4] a lifetime of exposure in a residence (assuming 75% occupancy) with an annual average RDC of 0.1 WL represents an increased risk of lung cancer of about 9%.

The chance of incurring a fatal lung cancer from any source (other than radiation) is about 3% in the U.S. population. This effectively means the average person typically has 3 chances in 100 of incurring a fatal lung cancer.

The added risk incurred by a lifetime of residence in the Monticello, Utah home was about four times the normal risk. Although the store had a higher annual average RDC than the house, the increased risk of a lifetime of working in the store is about the same as living in the house because of the fewer hours per day normally spent there. While this may not seem like a significant risk at first glance, it must be realized that a lifetime of living or working in these two buildings effectively quadrupled the occupants' chances of incurring lung cancer.
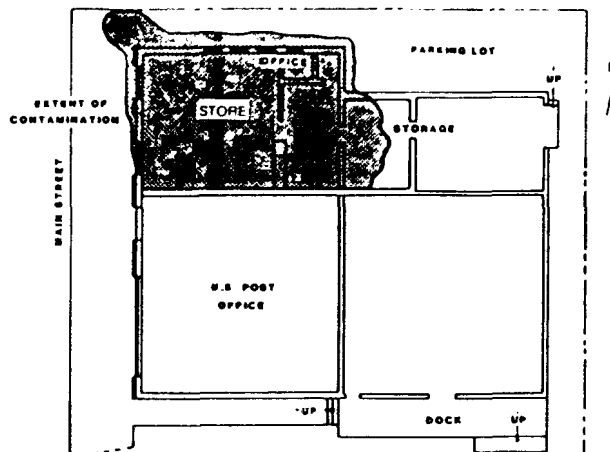
Figure 4
Plan View of Site, Showing Contaminated Areas
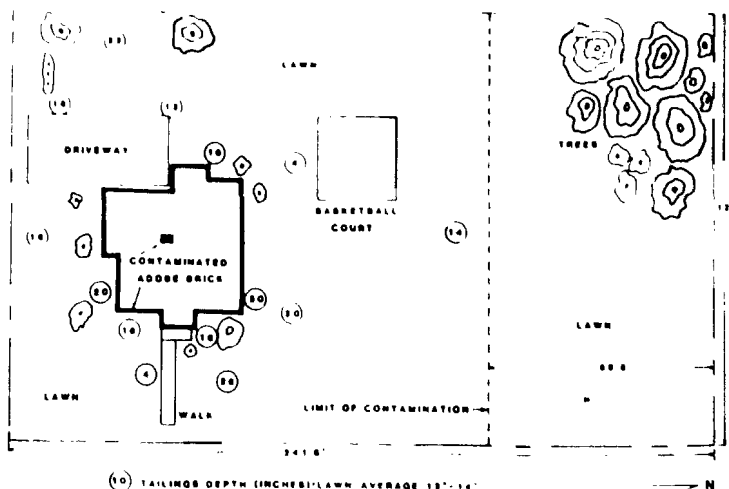
Figure 5
Plan View of Residence and Lot, Showing Location of Contamination

RESPONSE AND REHABILITATION

In early 1981, the USDOE contracted for an engineering assessment and remedial action plan for the two most contaminated structures in Monticello; a mail-order catalog store and a private residence. The resulting assessment provided detailed plans for demolition and reconstruction of the two structures and removal of the contaminants from the sites. Before work could begin, however, the USDOE determined that it lacked the legal authority to clean up the properties and suspended any further mitigation actions.

After it was determined that the USDOE did not have authority to clean up the two sites, the State of Utah and USDOE requested that the USEPA clean them up under CERCLA. CERCLA provides three main avenues of response to releases or potential releases of hazardous materials into the environment. These are: (1) an immediate cleanup or removal action if an emergency situation exists—the State is not required to provide any matching funds; (2) a planned removal action (short-term response) for site work taking less than six months and $1 million to complete; (3) a remedial action (long-term response) for site work taking more than six months and $1 million to complete. Approval of the request was denied on June 14, 1982, because the USEPA determined that the sites did not meet the regulatory requirement for a planned removal action. A threat must exist at the site which, if left unmitigated, would result in the need for an immediate removal action according to the draft National Contingency Plan of 1980. However, that particular section was modified in the final NCP, promulgated in 1982 and the request was resubmitted based on the concern that the "public and/or environment would be at risk from exposure to hazardous substances if response is delayed at a release not on the National Priorities List" [National Contingency Plan, 40 *CFR* Part 300.67 (a) (2)]. Approval of this new request was granted on July 14, 1983, and USEPA Region VIII, the State of Utah and USDOE completed the assessment and response actions described below.

Contracting

During the spring and summer of 1983, the USEPA and the State of Utah negotiated a contract for the conduct of a CERCLA Planned Removal Action with the USEPA taking the lead role. In July, 1983, the USEPA approved the Action and the following September, Utah signed the USEPA/State contract, agreeing to a 10% cost share in the project and thereby allowing it to proceed. Utah agreed to monitor on-site activities through a local Sanitarian attached to the District Health Department and to assist in implementation of the Community Relations Plan developed by the USEPA.

In the fall of 1983, initiation of the planned removal action was delayed due to insufficient time remaining to complete the project before the onset of winter. Monticello, on a plateau at 7000 ft above sea level, experiences generally harsh winters and any work involving the pouring of concrete outdoors becomes very difficult. Therefore, the USEPA decided to complete its arrangements for cleanup so that construction could begin early in the spring of 1984. These arrangements included negotiation of an Interagency Agreement (IAG) with USDOE to use their expertise and contractors for the actual cleanup work.

In January, 1984, the USEPA concluded the IAG with the DOE; the USDOE would act as the USEPA's prime building contractor during the removal, overseeing the development of the site specific Health and Safety Plan, the contract bidding process, the mitigation activities (i.e., demolition, removal and reconstruction) and the final decontamination certification. USDOE agreed to carry out these on-site activities and assigned a resident Building Inspector to oversee construction.

Health and Safety

As part of the decision process leading to the planned removal action, a health risk assessment was made for the occupants of both the store and the house. The owner of the house had voluntarily relocated his family for the winter, thus eliminating any additional radiation exposure to them, but the operator of the store planned to occupy it until cleanup began. The staff in the store would thus incur additional radiation exposure during the winter months unless some interim measures were taken. The USEPA Technical Assistance Team (TAT) was therefore directed to investigate measures to reduce, temporarily, the elevated radon daughter concentrations in the store.

Using information provided by previous on-site measurements, the TAT concluded that either air cleaning or additional ventilation could provide the desired degree of reduction. Both concepts were evaluated for the expected radon daughter reduction (RDC), operating costs, ease of installation and the degree of disruption of the store personnel. The TAT subsequently recommended the installation of two 650 ft^3/min electrostatic precipitators just below ceiling level in the main showroom area (Fig. 2) to maximize air circulation. The installation was completed on November 30, 1983, and the effect on the RDC was immediately apparent.

While this reduction was most impressive, it was only considered as an interim measure because the efficiency of the air cleaners was dependent on periodic cleaning and because this action had no effect on the gamma radiation exposure rate which was a secondary hazard. The latter could best be reduced by removal of the radioactive material.

The store was vacated by the lessee, at his own expense, on Mar. 10, 1984. On Mar. 14, after worker health and safety briefings were conducted by USDOE, the building subcontractor moved on-site and began demolition.

The store was a rectangular (28 ft x 40 ft), slab-on-grade structure built in 1945 and located along the Monticello main street. The mill tailings had been incorporated into the adobe blocks which formed the structure walls and an old chimney. They were also used as backfill under the floor slab (Fig. 4). The only uncontaminated parts of the structure were the roof and the footings. During demolition, small areas of contamination were also found under the floor of a rear storeroom and under the asphalt of the parking lot. Structures located immediately adjacent to the store were built at a later date and were not contaminated.

The entire structure, except for the footings, was demolished and the contaminated material was removed to a nearby USDOE-controlled tailings disposal site south of town by March 22. After removing the floor slab, approximately 16 in. of contaminated backfill were excavated. In all, 130 yd^3 of material were removed. USDOE and the Utah Bureau of Radiation Control monitored the action to ensure that all contaminated materials were removed before allowing reconstruction to begin. After a final inspection, the leasee resumed occupancy on May 20, 1984. Subcontract costs for rehabilitation of the structure were $73,000.

The house, built in 1944, is a roughly rectangular (35 ft x 41 ft), two-story structure with a full basement situated on a 125 ft x 214 ft landscaped lot. During construction, mill tailings were incorporated into the adobe blocks comprising the main floor exterior walls and the central chimney. Radioactive tailings were also used as backfill around the basement walls and to fill in depressions around the lot (Fig. 5). Preliminary readings, taken during the engineering assessment, indicated that tailings were as deep as 4 ft around the foundation. The foundation itself, the upper story of frame construction above the adobe and the roof were uncontaminated.

Under provisions of CERCLA and the NCP, the USEPA may remove contaminants during an authorized Removal Action and repair any damages caused by or during the removal, restoring the property as nearly as possible to the original condition. Replacement or relocation, however, is not permitted except under the Remedial Program provisions of CERCLA and was thus not possible for this Removal. In this instance, the property owner requested that the USEPA completely demolish the 40-year-old house and replace it with a smaller, slab-on-grade house sufficient to his current needs. He felt that this would be a less costly

approach and therefore a more reasonable utilization of CERCLA funds. However, the Removal provisions of CERCLA preclude any substantial modification to original designs over and above those necessary to upgrade the swelling to meet current building codes.

The actual Removal involved two separate but related operations: (1) rehabilitation of the structure, and (2) rehabilitation of the lot. Following a health and safety briefing for the building contractor by USDOE on June 6, 1984, the work crew moved on-site and began removing the house contents to a temporary storage area. After the contents had been stored, a frame support structure for one of the second story walls was fabricated and installed. After installation, the first floor adobe walls below the support structure were removed and a new frame wall was built. After this partial demolition/reconstruction, the support structure was moved to the next wall and the operation was repeated—so on until all the outside walls had been rebuilt. In this manner, the first floor ceilings, second story walls, and the roof were preserved intact. During this same period, the adobe chimney was removed and replaced with new brick.

As soon as the major construction on the house was completed to the point where it could be sealed against recontamination by airborne dust and dirt, excavation of the tailings from areas around the yard began. In all, approximately 1200 yd³ of contaminated material were removed to the nearby USDOE disposal site. Clean soil was brought to the lot and used to backfill the depressions. Smaller shrubs were removed, as necessary, along with the excavated tailings and replaced with local nursery stock. Where possible, tailings around the larger trees were hand-excavated in order to preserve the trees. As before, the USDOE and the Utah Bureau of Radiation Control were on hand during the tailings removal to monitor the action and ensure that all contaminated materials were completely removed. The entire lot was then covered with new sod.

Subcontract costs for the structure rehabilitation and tailings removal from the yard approached $129,000 when the removal was completed in mid-September 1984.

CONCLUSIONS

Elevated levels of radon daughter products were discovered in two structures in Monticello, Utah. The radiation source was radioactive mill tailings sand (a waste residue from ore extraction processes) used as fill and building material when the structures, a house and a store, were built during the mid-1940s. The tailings, which contained small amounts of uranium and radium, originated from a local World War II-era vanadium processing mill. USDOE, present-day custodian of the millsite, determined that it did not have the legal authority to address the health threat to the occupants of the structures, the USEPA undertook a Superfund Planned Removal Action to eliminate the exposure source and the associated health threat.

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BIDDING CONSIDERATIONS FOR SUPERFUND CLEANUP CONTRACTS

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INTRODUCTION

In the last 2 years, procedural errors by contractors submitting bids for Superfund cleanup contracts advertised by the U.S. Army Corps of Engineers (Corps) have occurred frequently. Often these errors have resulted in the disqualification of otherwise capable contractors. Bid documents from past cleanup projects have been reviewed and the procedural problems analyzed. This paper is intended to clarify the Corps procurement method and identify common or recurrent bidding errors.

BACKGROUND

The USEPA and the U.S. Army Corps of Engineers entered into an Interagency Agreement (IAG) on Feb. 3, 1982. The IAG identifies those activities for which the Corps will be responsible. One such assigned activity is the procurement of construction contracts for the cleanup of Federal Lead Superfund Sites. Wording in the IAG allows the Corps to utilize existing procurement methods for design and construction contracts. These contracting methods are based on the Federal Acquisition Regulations and are supported by years of experience.

The Corps has chosen a design center approach for the contracting, review and coordination of project design. Nationwide, the Missouri River Division (MRD) has been assigned responsibilities for all activities from technical assistance during the remedial investigation/feasibility study phase to award of the construction contract. Therefore, MRD, through its district offices at Kansas City and Omaha, retains responsibility for a project during the procurement phase. The Kansas City District is the lead district for USEPA Regions II, IV, VI, VII and X. Omaha is lead district for Regions I, III, V, VIII and IX.

The method most commonly used by the Corps of Engineers for cleanup activities is formally advertised competitive bidding. This method requires that the contractor submit a firm bid price to perform all work identified by the plans and specifications accompanying the Invitation for Bids. In rare cases, a Request for Proposals under a negotiated competitive procedure may be used. Under the negotiated procedure, prospective contractors are required to submit a proposal outlining the methods and approaches by which they will comply with the specifications. The evaluation and award procedure for negotiated contracts differs greatly from that of the advertised procurement but will not be discussed here because of the projected limited use of the negotiated procedure. The contract format used will normally be a standard construction contract containing standard construction General Clauses, Special Clauses, Davis-Bacon rates, etc. A service contract format may be used when the majority of the work to be performed is other than that considered to be construction-related. While the standard bid forms, General Clauses, and Specifications format may differ from the construction format, the bid requirements for both service and construction contracts are very similar.

BID PROCEDURES

As indicated above, the method most commonly used by the Corps of Engineers is a construction contract for advertised competitive bidding. The procedure begins with the advertisement of the proposed project in the *Commerce Business Daily,* commonly 30 days prior to bid opening. In addition, an advance notice of the proposed contract is mailed to a list of prospective bidders who have expressed an interest in the specific type of work. For Superfund projects, a separate list of prospective bidders will be maintained by the Kansas City and the Omaha Districts. The Invitation for Bids establishes a place, date and time at which a public bid opening will be conducted. In order for a bid to be considered for award, it must be received at the place designated prior to the date and time established for the bid opening. The only exception relates to mishandling of a bid sent by Registered Mail at least 5 days in advance of the opening date. The instructions in the Invitation for Bids specifically detail the application of this exception.

After public opening, the apparent low bid is reviewed by the Corps' procurement personnel. The design district retains responsibility for a project until the contract is awarded. Therefore, preparation of bid documents, advertisement, amendments, bid opening and award are all coordinated by one Corps office. Bids are reviewed to ascertain if they are responsive and if the bidder is responsible. Responsive relates to compliance with contractual requirements. A change, addition or omission to the bid documents which affects the enforceability of the contractk limits the contractor's responsibilities to less than those specified or would allow the contractor to acept or reject the contract as he chooses, makes the bid nonresponsive. Such errors are normally cause for rejection of the bid. Responsibility pertains to the contractor's ability to perform the work. Itsme such as the contractor's experience and letters from disposal facilities reflect responsibility. Such items may require further clarification during bid review.

BIDDING INFORMATION

Information describing bid procedures is contained in several sections of the project specifications. These may include:
- Invitation for Bids
- Instructions to Bidders
- Bid Form

- Special Clauses
- Representations and Certifications
- Measurement and Payments

Each section should be read carefully to assure that appropriate guidance is reflected in the bid documents as submitted. Often errors can be avoided if bid requirements are reread and all possible information assembled well before bid opening. Unlike questions regarding the technical portion of the specification, which should be submitted in writing and responded to by amendment, questions regarding procurement can usually be handled quickly and informally. In fact, a separate contact is often provided for procurement related questions.

BID REVIEW

The following discussion is intended to reflect the more common errors made by past bidders. It is not to be construed as a complete list of all possible errors.

Bid Form

- Bids must be submitted on the form supplied with the specifications or on a copy of that form.
- All numbers and written information must be clear and legible. If erasures or other changes appear on the forms, each erasure or change must be initialed by the person signing the bid. The bid price must be based on construction as described in the project specifications.
- The bidder must not submit a bid based on alternative means or methods not provided for in the contract.
- The bid form must be complete and unaltered. Qualification of a bid, any addition or change to the bid form which alters contract requirements or affects contract price, is cause for disqualification.
- Failure to acknowledge receipt of all amendments can result in rejection of the bid.
- The bid form may require a single bid amount or it may require prices for more than one bid item. When the bid form requires the contractor to submit prices for all items, failure to do so will disqualify the bidder.
- When submission of a price on all items is not required, bidders should insert the words "no bid" in the space provided for any item on which no price is submitted.
- All bid forms must be manually signed.

Bid Guarantee

- Where a bid guarantee is required by the invitation to bidders, failure to furnish a bid guarantee in the proper form and amount, by the time set for opening of bids, may be cause for rejection of the bid.
- Acceptable forms of the bid guarantee are described in the Instructions to Bidders.
- The amount of the guarantee, usually described in percent of the total bid price, is presented in the Invitation for Bids.
- Usually, the bid bond amount may be expressed in terms of a percentage of the total bid price or expressed in dollars and cents.
- The bid guarantee must be manually signed.

Power of Attorney

- When the bid guarantee utilized is a bid bond, the bond is usually accompanied by a Power of Attorney, authorizing an agent to act on behalf of an insurance company.
- The Power of Attorney must be properly completed and signed.
- The date must be such that it is effective when the Bid Bond is signed and the bids are opened.

- The Power of Attorney must not restrict the financial authority to an amount less than that required by the contract documents.

Additional Requirements

- The contract documents often require the bidder to submit additional information as part of the bid. The documentation required will be described in the Invitations for Bids or the Bid Form.
- "Representations and Certifications," Standard Form 19B, is included in the project specifications and is to be submitted with the bid.
- Available plant, bidder qualifications and evidence of experience are all items which the bidder may be required to document.
- The bidder may be required to include with the bid the qualifications and a letter of commitment from subcontractors responsible for transportation of hazardous materials and disposal facilities.
- The sections addressing these requirements should be read carefully to ensure that all requirements are met.

Submission of Bids

- Bids must be sealed, marked and addressed as directed in the Invitation for Bids.
- Information regarding withdrawal, modification and late receipt of bids is presented in the Instructions to Bidders.
- Bids will be publicly opened at the time and place set for opening in the Invitation for Bids.

PROTESTS

To ensure that Corps procurement actions are fair and that procedures are consistently applied, there is a protest mechanism available to the bidders. By submitting a written protest to the office issuing the Invitation for Bids, the contractor can bring an issue to the Corps attention. The issue will then be reviewed and evaluated to ascertain its validity. A response is prepared and forwarded through administrative channels to the office designated to decide the validity of the protest.

Unfortunately, the review which follows a protest can be time consuming and may hold up award of the contract, thereby delaying initiation of cleanup activities and, since the evaluation is based strictly upon adherence to the applicable laws and regulations which affect the procurement, it is an unsuitable forum for addressing any issue not directly related to the action. The protest privilege provides the bidder with recourse, but restraint must be used to avoid abuse.

CONCLUSIONS

Current information indicates the number of Superfund cleanup contracts awarded will increase dramatically over the next few years, and it is anticipated that Corps-procured contracts will increase proportionally. The Corps' procedures, while not simple, are necessary for legal and administrative reasons. Most procedural errors can be eliminated by careful review of the project specifications and early preparation of those forms and documents which lend themselves to such action. Questions concerning procurement can be answered expeditiously by a Corps contact, identified in the Invitation for Bids.

Rejected bids represent a loss to all involved. To the contractor, it means lost effort in preparing the bid and a lost contract opportunity. To the Superfund program, rejected bids mean higher contract prices and, too often, delays associated with protests. The Corps appreciates the efforts of participating contractors and looks forward to continuing interest and cooperation in accomplishing what it considers a most important national program.

THE U.S. ARMY INSTALLATION RESTORATION PROGRAM

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Aberdeen Proving Ground, Maryland

INTRODUCTION

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) is currently conducting a long-range program to determine what Army installations throughout the United States are contaminated with hazardous wastes from past operations and to initiate corrective actions if the wastes present a real or potential hazard to man or the environment. As part of its mission, the Agency is also responsible for evaluating and removing, as warranted, hazardous wastes on properties that are scheduled for release from the Army for use by others. The program, known as the Army's Installation Restoration Program (IRP), has been ongoing for the past nine years and has become the model for the Department of Defense (DOD) program to assess and control the migration of environmental contamination that may have resulted from present or past disposal activities.

The base level of funding for the IRP has been in excess of the $16 million estimate since all the identified problems have not been quantified and the lack of criteria or standards for cleanliness requires that each remedial action be negotiated with the appropriate state and Federal regulatory authorities.

BACKGROUND

The Army's IRP predates CERCLA by five years. Presidential Executive Order 12316 delegated certain authority specified in CERCLA to the Secretary of Defense, and DOD was authorized oversight over its own program by the Executive Order, thus separating it from CERCLA or "Superfund."

Within DOD, the Secretary of Defense's authority in Executive Order 12316 was redelegated to the Secretaries of the Army, Navy and Air Force. The Assistant Secretary of Defense for Manpower, Reserve Affairs and Logistics on Nov. 20, 1981, formally identified DOD's functioning IRP as the DOD Superfund program.[1] The objectives of the IRP are these:

- To identify and evaluate past hazardous material disposal sites on DOD facilities; to control contamination migration that presents a hazard to health or welfare
- To review and decontaminate as necessary land and facilities excess to DOD's mission

In the Defense Environmental Quality Program Policy Memorandum (DEQPPM) 81-5, dated Dec. 11, 1982,[2] DOD required that the military departments and the Defense Logistics Agency establish and operate their own IRP. Two separate but related requirements led to the creation of the Army's IRP in 1975. FIRST, the Army was faced with regulatory agency action at several installations where past waste disposal practices had caused contamination of surface streams and groundwaters. In the spring of 1974,

pollutants were found in water migrating from Rocky Mountain Arsenal (RMA), Commerce City, Colorado. This prompted the Army to take corrective action and also to take a close look at past military operations at other installations in an effort to determine if they could be causing similar contamination problems.

The SECOND requirement for this program was the need to decontaminate Army-owned real estate that was considered excess to Army needs. Efforts were needed to insure the property presented no health or safety hazards upon its transfer to future users.

The initial installation restoration charter specifically designated RMA and Weldon Spring Chemical Plant ([WSCP] Missouri) as priority tasks for the IRP. The contamination at RMA has been a matter of public and Congressional concern for more than 25 years. WSCP, on the other hand, is part of a former Army munitions plant that was later used by the then Atomic Energy Commission (now the Department of Energy) for nuclear ore processing. It is no longer needed by the Army, but cannot be released for general use due to radiological contamination.

Most of these problems were not caused by neglectful management practices or a disregard of environmental regulations. Rather, they represent the consequences of following industrial and waste handling practices that were approved and common at the time.

The complexity and magnitude of the Army's requirements in these areas were also rapidly defined. While the Army's environmental problems were similar to those in the civil sector, several factors indicated a need to establish an in-house technical capability in this area. (1) Since the Army has facilities located throughout the United States, it was faced with contamination problems under an infinite variety of climatic and geohydrological conditions. (2) Due to the diversity of the Army's manufacturing, testing and training missions, the full spectrum of contamination problems was being discovered. These ranged from surface soil contamination and associated runoff problems in the vicinity of industrial sites to groundwater contamination below active and former landfills. (3) Many of the contaminants were determined to be unique to the military's defense mission, e.g., wastes and by-products from munitions production or testing activities. For these compounds, insufficient human health or environmental hazard data were available to define risk levels and, therefore, identify the extent of the necessary control effort.

In recognition of the complexity, high cost, involvement of a wide range of Federal and state agencies and the overall impact of such an undertaking, the Assistant Secretary of the Army for Installations and Logistics directed that the Army's installation restoration efforts by placed under project management control. This organization, the Department of the Army (DA) Project

Manager for Chemical Demilitarization and Installation Restoration, since redesignated USATHAMA, is located at Aberdeen Proving Ground, Maryland.

The first task was to identify both those Army installations known or suspected of containing contamination as a result of past manufacturing, testing or disposal activities and also those installations earmarked for excessing. Priority was given to installations where contamination was or had a high potential for migrating beyond installation boundaries. Some 66 installations were initially identified, and an assessment program was begun. In the intervening nine years, the list has grown steadily and now totals some 197 sites.

The primary hazardous wastes of concern on Army properties from past operations are residues from explosive-related operations, spent volatile organic solvents and heavy metal residues from combat vehicle and metalworking operations.

IRP DESCRIPTION

The basic IRP structure is outlined in DEQPPM 81-5. The concept plan is divided into four specific phases: (1) installation assessment, (2) confirmation, (3) technical data base development and (4) operations.

Installation Assessment

Phase I of the IRP is an installation assessment study designed to be completed within nine months. The DOD goal under DEQPPM 81-5 is to complete all records search reports by the end of FY85.

In this phase, installation files are examined, current employees and key former employees are interviewed and the terrain and facilities are examined. Additionally, all available information on past mission, current operations, waste generation, disposal and hydrogeology of the area is collected. Limited soil and water sampling may also be conducted to determine if contaminants are present. A decision to proceed to the next phase comes at the end of the records search is the results show a potential for migration at hazardous levels.

Confirmation

Phase II is referred to as the confirmation phase. Phase II preliminary survey studies are designed to be completed in one year. If a comprehensive survey were required, the time would extend at least another year.

In this phase, preliminary and comprehensive surveys are conducted to fully define the problem through environmental sampling and analysis. Data are developed to fill identified information gaps revealed during Phase I, and survey data from all technical areas are interpreted and interrelated. A decision point is included after the preliminary survey to determine if a confirmation survey is needed to fully define the migration problem.

Technical Data Base Development

Phase III is referred to as technology base development. In this phase, control technology is matched with specific contamination problems at a given site to determine the most economical solution. If control technologies do not exist, they are developed in this phase. The length of Phase III studies varies significantly; one to two years is an acceptable time for completion. In the case of research and development, time may extend longer is regulatory agencies require or demand pilot testing prior to granting acceptance of a technology for treatment/disposal.

Operations Phase

Phase IV of the IRP is the operations phase. This phase includes design, construction, operation of pollution abatement/control facilities and the completion of remedial actions. This phase could include the construction of containment facilities or decontamination processes and associated long-term monitoring systems. Phase IV operations range from a matter of months to multiyear remedial actions.

MANAGEMENT APPROACH

The engineering management approach and studies used to define contamination migration problems and to address their resolution are outlined in Figure 1.

The first step is a "Records Search" which is conducted on-site by a team of engineers, chemists, a geologist and an environmentalist (biologist or zoologist). This team reviews old files, interviews present employees and retirees, examines the terrain and facilities from the air and the ground and collects all available information relating to mission operations, waste generation and disposal and geohydrology of the area. These data are then compiled and evaluated to determine the potential for hazardous migration. Should such potential exist, limited investigative water and soil sampling and analyses could be performed to validate or invalidate that migration potential. If these limited investigations prove positive, a thorough survey of the installation is made to completely define the pollution sources and pathways. The necessary restoration technology to eliminate or contain the migrating contamination is developed, piloted and put into operation.

Throughout this process, financial and personnel resources are expended only at a level necessary to permit decisions concerning migration potential and probable remedial actions. Through this approach, the Army is developing a substantial data base of information and problem solving methodologies that are potentially applicable not only to the installation being studied but also to other sites.

INSTALLATION ASSESSMENT

Records Search

The Records Search Program began in 1976. The current DA IRP includes 197 installations (including 14 reevaluations) assessed by the end of FY85. By Sept. 30, 1984, the on-site visit phase was completed. There were 153 reports representing 189 sites completed and published at an average cost of $39,343 per site. A summary by major Army command is given in Table 1. The remaining five reports representing eight sites will be published by the end of FY85 in response to DOD direction.

Between 1976 and 1981, records search tasks were performed by the Chemical Systems Laboratory, now known as the Chemical Research and Development Center of Aberdeen Proving Ground, Maryland. The decision was made in 1981 to contract the remaining program with private industry.

As the records search program was getting underway, the Army learned in 1978 that it had an unsuspected legacy in some of its former properties. Interest by the State of New York following the Love Canal story led to inquiries about Lake Ontario Ordnance Works (LOOW) in Lewiston, New York. LOOW had produced trinitrotoluene [TNT] during World War II. It, and many other facilities like it around the United States, were sold after the war. This inquiry and others like it caused the Army to perform 21 archive searches (Table 2) to identify these former properties and potential problems that might need attention.

Most plants ceased operations immediately following World War II; some reopened during the Korean Conflict; and other properties such as Nike sites were opened during the 1950s and 1960s to be closed in the early 1970s. When the doors to these places were shut, environmental concerns were not an issue; disposal by burial or dumping was an acceptable practice and decontamination, which was required and performed at that time, did not meet today's standards.

Because some of the sites were found to be potential problems, remedial actions were initiated. Work is currently underway by USATHAMA at Phoenix Military Reservation ([PMR] Nike site in Maryland) and West Virginia Ordnance Works (WVOW), Point Pleasant, West Virginia. During 1984, the Corps of Engineers Civil Works was tasked to assume responsibility for all formerly owned sites within DOD. That program is now underway; however, the prior owning service has the first option to conduct the necessary environmental work if it so desires.

Table 1
Summary of Recorded Searches Performed by Major Army Commands

Installation Assessment Program, FY76-85

Major Command	Initial Assessments	Reevaluations
DARCOM	85	13
FORSCOM	50	
TRADOC	25	1
WESTCOM	9	
DLA	7	
MTMC	3	
HSC	3	
MDW	3	
COE	4	
INSCOM	2	
USMA	2	
CC	1	
OTHER	2	
TOTAL	196	14

Table 2
List of Archive Studies Performed on Formerly Owned Army Properties

Archive Studies

Arkansas Ordnance Plant Jacksonville, AR	Nebraska Ordnance Plant Mead, NE
Black Hills Ordnance Depot Igloo, SD	New York Ordnance Works Baldwinsville, NY
Chickasaw Ordnance Works Millington, TN	Nike Batteries—General Search
Cold Spring Battery Plant Cold Spring, NY	Plum Brook Ordnance Works Sandusky, OH
Erie Ordnance Depot Port Clinton, OH	Providence Defense Area Nike Batteries RI
Freeman Army Air Field Seymour, IN	Raritan Arsenal Metuchen, NJ
Illinois Ordnance Plant Carbondale, IL (Crab Orchard)	Santa Rosa Army Airfield CA
Jeffersonville Quartermaster Depot Jeffersonville, IN	St. Louis Ordnance Plant St. Louis, MO (Hanley Area)
Kingman Army Airfield AZ	Schenectady General Depot Schenectady, NY (Guilderland)
Kingsbury Ordnance Plant La Porte, IN	West Virginia Ordnance Works Point Pleasant, WV
Lake Ontario Ordnance Works Lewiston, NY	

Confirmation Surveys

Since 1979, Phase II surveys have included both exploratory and confirmatory phases. The basis for this approach was to spend only those resources needed to obtain the information necessary to show an existing problem before proceeding with a full scale survey of the installation. The exploratory phase generally determines if contamination is migrating—if not, no confirmatory phase is necessary. If yes, the confirmatory phase defines sources and extent of migration.

A total of 57 exploratory surveys were recommended either as a result of the Records Search Program or by the direction of higher headquarters. A detailed listing by installation is shown in Table 3. So far, 28 surveys have been completed, 18 are ongoing, five are scheduled for initiation during FY85, two are in abeyance pending receipt and evaluation of data being generated by the installation and four are being performed by other than USATHAMA.

The average cost of all surveys was about $344,000 (Fig. 2). These data show that 61% of the surveys cost less than $300,000 (actual average, $205,238). Inclusion of the four surveys that cost between $300-$400K incorporates 73% of all surveys performed at a total average cost of $224,560. The six surveys costing greater than $600K were the more complex projects including Anniston Army Depot (Alabama), Alabama Army Ammunition Plant (Alabama), Letterkenny Army Depot (Pennsylvania), Joliet Army Ammunition Plant (Illinois), Twin Cities Army Ammunition Plant (Minnesota) and Frankford Arsenal (Pennsylvania). RMA also cost in excess of $600K but is not represented.

TECHNICAL DATA BASE DEVELOPMENT

For the most part, this phase is now combined with the confirmation survey portion of the assessments phase providing a streamlined effort performed as a concurrent rather than sequential effort. Projects which can currently be considered in this phase are RMA, Anniston Army Depot, Letterkenny Army Depot, Twin Cities Army Ammunition Plant, Sharpe Army Depot (California), Milan Army Ammunition Plant (Tennessee), PMR (Maryland) and Cornhusker Army Ammunition Plant ([CAAP] Nebraska). Projects which have gone through this phase are Redstone Arsenal (Alabama), Pine Bluff Arsenal (Arkansas), Frankford Arsenal, RMA and Anniston Army Depot.

The Army has faced several problems in conducting this phase of the investigation:

● For many of the hazardous problems encountered, there are no known standards or criteria. It leaves the Army with the "How clean is clean?" problem which is not easy to solve and relates to the next point.

● State standards and methods of operation are not homogeneous or even published. Some are more actively pursuing environmental problems than others. The result is that the Army has to negotiate with each individual state to establish acceptable residual contaminant levels and methods of treatment or non-treatment.

OPERATIONS

The 26 installations where remedial actions have been performed or actions are required are listed in Table 4. The most significant limitation on remedial action operations is the lack of working or proven alternative technologies needed to cleanup currently identified problems caused by explosives or organic solvents. One either digs up the contaminant and moves it somewhere else or covers it in place. In the case of groundwater/aquifer contamination treatment, no such action has proved to be a practical alternative.

More competitive pressure needs to be placed on industry to provide solutions incorporating technologies that not only reduce the enormous cost of transportation but also eliminate the deferral of the problem or residual liability caused by burying hazardous material in different "secure" landfills around the country. While the USATHAMA technology development program (described below) will produce potentially usable technology, the Agency needs it now but does not have it.

CASE HISTORIES

Anniston Army Depot

Anniston Army Depot, located in northeast Alabama, originally was an ammunition storage depot. During World War II its mission expanded to include combat equipment storage. Over the years, it evolved into what is now the major tank rebuild facility in the free world. Industrial processes at Anniston Army Depot led to the production of waste chemicals, mainly degreasing solvents and metal-processing sludges.

In 1980, samples of monitoring wells showed these hazardous wastes had entered the groundwater and appeared to be migrating from two former disposal areas located within the southeast industrial area of the Depot. USATHAMA subsequently initiated a survey and assessment to determine the extent of hazardous contamination migration and to develop plans for abatement or treatment as required. The program consisted of four tasks:

Table 3
U.S. Army Survey Program Summary

SURVEY STATUS

INITIATED/COMPLETED	INITIATED/ONGOING	INITIATION/SCHEDULED
FY	FY	FY
77 Aberdeen PG (EA), MD	81 Anniston AD, AL	85 Bayonne MOT, NJ
79 Alabama AAP, AL	84 Detroit Arsenal, MI	85 Sunflower AAP, KS
79 Badger AAP, WI	83 Ft. Belvoir, VA	
81 Blue Grass DA, KY	84 Ft. Drum, NY	*Survey pending review
80 Camp Simms, DC	81 Indiana AAP, IN	of sampling data from the
81 Cornhusker AAP, NE	80 Iowa AAP, IA	U. S. Army Environmental
80 Ft. Gillem, GA	80 Joliet AAP, IL	Hygiene Agency and the
79 Ft. Monroe, VA	81 Letterkenny DA, PA	State of Maryland
80 Ft. Wingate DA, NM	81 Lone Star AAP, TX	
78 Frankford Arsenal, PA	82 Longhorn AAP, TX	In Abeyance
82 Gateway AAP, MO	84 Natick (Sudbury), MA	
78 Hawthorne AAP, NV	84 Phoenix Military	Holston AAP, TN
81 Lexington DA, KY	Reservation, MD	Aberdeen PG (AA), MD
81 Louisiana AAP, LA	84 Riverbank AAP, CA	Ft. Meade, MD
80 Michigan AMP, MI	76 Rocky Mtn Ars, CO	
79 Milan AAP, TN	81 Twin Cities AAP, MN	Other
80 Navajo DA, AZ	83 Vint Hill Farms, VA	
76 Pine Bluff Arsenal, AR	81 Volunteer AAP, TN	DLA - Ogden, UT
80 Providence NIKE, RI	84 West Virginia Ord	DLA - Richmond, VA
79 Redstone Arsenal, AL	Wks, WV	DLA - Memphis, TN
80 Sacramento AD, CA		Ft. Detrick, MD
82 St. Louis ASC, IL		
79 St. Louis OP, MO		
80 Savanna DA, IL		
81 Sharpe AD, CA		
81 Tooele AD, UT		
80 Umatilla DA, OR		
77 Weldon Spr CP, MO		

Table 4
U.S. Army Remedial Action Program Summary

INITIATED/COMPLETED	INITIATED/ONGOING	INITIATION/SCHEDULED
FY	FY	FY
81 Alabama AAP, AL	84 Cornhusker AAP, NE	* Alabama AAP, AL
(Leaseback Area)	83 Joliet AAP, IL	(GSA & Ind Areas)
82 Anniston AD, AL	84 Milan AAP, TN	87 Iowa AAP, IA
79 Frankford Ars, PA	78 Rocky Mt Ars, CO	85 Letterkenny AD, PA
82 Gateway AAP, MO		86 Louisiana AAP, LA
76 Pine Bluff, AR		85 Phoenix NIKE, MD
80 Providence NIKE, RI		86 Savanna DA, IL
79 Redstone Ars, AL		86 Sharpe AD, CA
79 St. Louis Ord Plant, MO		85 Twin Cities AAP, MN
83 Santa Rosa AAF, CA		86 Volunteer AAP, TN
		85 West Virginia Ord Wks, WV
* Not Presently Scheduled		85 Woodbridge Research
		Facility, VA

Geotechnical Evaluation

Task One, the geotechnical evaluation, was accomplished during April to September 1981. Surface remote sensing techniques along with geohydrologic investigations were employed to evaluate the potential for groundwater contamination and its subsequent migration and movement into and within the bedrock. These techniques successfully delineated the horizontal and vertical boundaries of seven buried chemical sludge disposal trenches. In addition, these techniques provided insight to the direction of the shallow groundwater flow and the depth to and configuration of the bedrock. Based on these results and USATHAMA's concern that a potential existed for contaminant migration into the bedrock, the disposal of hazardous wastes in the seven chemical sludge trenches was discontinued.

Groundwater Quality Assessment

Task Two planning was begun in August 1981, and a groundwater quality assessment plan was prepared by USATHAMA and provided to the appropriate regulatory authorities in October 1981. The objectives of the plan and subsequent assessment were to determine the concentration, rate and extent of migration of hazardous waste or hazardous waste constituents in the groundwater.
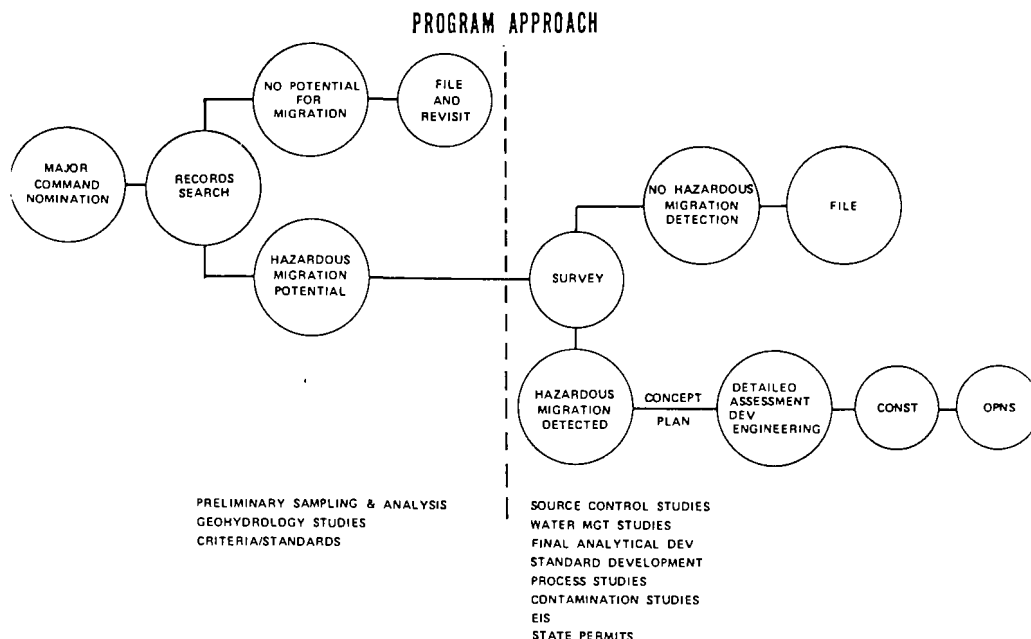
Figure 1
USATHAMA Approach to Determine Contamination Migration and Required Corrective Actions

The results of the assessment were published in an October 1982 status report.

Based on these findings which located new areas of groundwater contamination, a follow-on study involving computer simulation was completed to determine the sources of the contamination and to evaluate the feasibility of groundwater intercept and treatment systems. The study was provided to state and Federal regulatory authorities in June 1984 for review and comment.

Economic and Technical Analysis

Task Three, originally scheduled to begin in February 1982, was brought forward to August 1981 based on the geotechnical evaluation. USATHAMA's in-house expertise was utilized to complete this task which involved an economic and technical analysis of a variety of alternatives for closure of the chemical sludge disposal trenches and the old lagoon sludge pile. USATHAMA completed the alternatives analysis ahead of schedule, and a recommended approach for remediation was presented to the U.S. Army Material Development and Readiness Command, now the U.S. Army Material Command (Alexandria, Virginia), in November 1981 along with a request for funding. This approach, incorporating the most feasible technical and economic alternative, required the exhumation of the chemical sludge disposal trenches and other wastes for transportation and off-site disposal at a permitted disposal/treatment facility located in Emelle, Alabama.
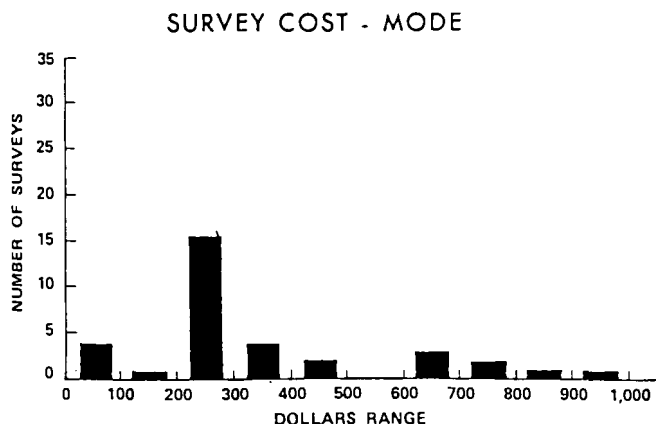
SURVEY COST - MODE

Figure 2
Mode Distribution of Exploratory Survey Costs ($000)

Closure

Task Four, the closure operations, began with the preparation of closure specifications in March 1982. Approval of these specifications was granted by the regulatory authorities in June 1981. Excavation of the hazardous wastes commenced in November 1982 and was completed in May 1983, removing 60,000 tons of waste and surrounding soil contaminated with spent organic solvents and heavy metals.

Cornhusker Ammunition Plant

Cornhusker Army Ammunition Plant was constructed in 1942 in Hall County, 4.0 miles west of Grand Island, Nebraska. Its primary mission was to load, assemble and pack a variety of conventional munitions containing TNT and cyclotrimethylenetrinitramine [RDX]. Industrial activity at CAAP was intermittent, depending on levels of military activity. Active production periods coincided with World War II, the Korean Conflict and the Vietnam Conflict. CAAP is currently in a standby status. Industrial waste generated at CAAP consisted primarily of washdown waters (containing TNT and RDX) resulting from loading and packing operations. These wastes were treated by means of filters, cesspools (dry wells) and leaching pits. CAAP did not discharge wastes to surface waterways. Liquid explosive wastes from past operations that were disposed into the cesspools and leaching pits at CAAP contaminated the shallow groundwater in a one square-mile area within the Plant's northeast boundary.

The survey revealed that the soils at the bottom of leaching pits used to collect ammunition manufacturing wastes during World War II and again during the Korean and Vietnam Conflicts are contaminated to a depth of three feet or greater with explosives; TNT, RDX, dinitrotoluene [DNT], their manufacturing by-products and their environmental degradation products. These contaminants leached into the underlying sand and gravel which contains the shallow aquifer.

Subsequently, results of the Army's groundwater monitoring program at CAAP confirmed the presence of explosives in the groundwater three miles beyond the Plant's eastern boundary. Chemical analyses of the 467 private wells sampled east of the installation detected the explosive compounds RDX, DNT and TNT in two wells within one mile of the Plant. However, RDX alone was found in 246 wells located up to three miles east of the installation boundary. At present, no regulatory standards have been established for any of these compounds. The Army, however, has

recommended interim water quality criteria for TNT and RDX based on toxicity studies which concur with the National Academy of Sciences. The USEPA has recommended a water quality criterion for DNT.

The Army is providing bottled water for drinking and cooking to those residents whose wells are affected as determined by local health authorities in conjunction with the Army. On July 31, 1984, the Army entered into contract with the City of Grand Island to extend the city water supply to the affected community at a cost of approximately $5 million dollars. In conjunction with the immediate measures needed to provide drinking water, other work to contain or abate the sources and contamination plume is continuing.

Frankford Arsenal

The Frankford Arsenal (Philadelphia, Pennsylvania) dates back to 1816. During its 161 years of operation a variety of activities including munitions manufacture, materials and research development activities, development of propellant and cartridge-actuated devices and a variety of procurement missions were accomplished at the Arsenal. In 1976, the facility was declared excess to ARmy needs and plans were put in place for the decontamination and cleanup of the Arsenal prior to transfer of the property to the General Services Administration (GSA) for subsequent disposition and release for unrestricted use.

In the spring and summer of 1978, a survey of the 110-acre Arsenal was conducted under contract. This survey identified low levels of: (1) heavy metals residues, (2) explosive residues and (3) radiological contaminants. Based on the results of this survey, bids were requested from various industrial contractors to perform decontamination and cleanup of the Arsenal. In September 1979, a contract for the Arsenal decontamination and cleanup was awarded.

The cleanup program was conducted in three phases. During Phase I, decontamination methods and procedures were verified. Detailed standing operating procedures were prepared during Phase II, and decontamination operations were conducted during Phase III. The contractor completed decontamination operations in November 1980. The Arsenal was subsequently sold by GSA in 1983.

INSTALLATION RESTORATION RESEARCH AND DEVELOPMENT TECHNOLOGY

Concurrent with the ongoing survey and restoration efforts, a technology development program has been initiated to obtain new and better detection and analytical techniques and containment and treatment processes. The areas being investigated include ecology, geotechnical studies, analytical systems technology, decontamination technology and management and retrieval of the myriad of data generated throughout the entire IRP. A synopsis of each area of efforts follows:

Ecology

In ecology, technology capable of defining pathways of migrating contaminants as determined by their efforts on selected environmental communities is being applied. Aerial infrared photo interpretation is being employed for establishing baselines for vegetation stress to determine the effectiveness of decontamination/ abatement measures for detecting potential sites for surface soil contamination and surface water migration as well as locations of landfills, burial sites and ditches.

Geotechnical

Geotechnical studies are underway to determine the nature of soils, bedrock, sediment, surface water, groundwater and their relationships to contaminant occurrence and movement. Development of a surface water and groundwater quality monitoring program involves locating stream monitor stations and drilling wells at positions which are indicative of the general groundwater situation.

Analytical

Due to the varied nature of installation restoration analytical requirements, the analytical methods program develops or adapts analytical procedures for particular needs in the parts per billion or parts per trillion range and implements these procedures in those laboratories conducting analyses for the Army. In some instances where the presence of only a few contaminants was anticipated based on the installation's past operations, environmental changes have transformed the compounds into potentially several hundred distinct components. Rapid and sensitive screening techniques are required to determine the qualitative presence or absence in a sample. New technology to meet these ever changing challenges is consistently being studied in research and development projects.

Decontamination

Many of the contaminants of concern are unique to the military, and large areas of contaminated soil, sediment and surface and groundwater represent technically complex decontamination problems and high treatment costs. Studies are underway to identify and develop novel and cost effective decontamination technologies in these areas.

Computerization

A network of computer terminals located at field installations has been connected to a main-frame Univac 1108 computer at Aberdeen Proving Ground where USATHAMA, the centralized management agency, is located. Data are collected through the terminals with mass storage of the data in the Univac.

Chemical, ecological and geological data are contour-plotted by the computer on digitized maps of field installations. Contamination plumes of various contaminants, in various media (soil surface water, groundwater, sediment and biological tissues) can be studied over time periods to determine location and direction of movement. A cost/benefit/risk analysis program for decision making in containment and/or treatment alternatives is being integrated into the simulation effort.

To date, approximately three million records have been received and automated on the computer. Software has been acquired or developed for plotting chemical plumes, species demography and some geological parameters; other programs have been developed for food chain presentation and mass flux calculations.

CONCLUSIONS

In this paper, the authors have briefly described the Army's IRP and some of its achievements to date. With over nine year's experience, the Army is confident that its technical approach and centralized management structure offer an effective mechanism to deal with the unique military environmental contamination problems. Recent discussions with the USEPA have revealed that the Army program conforms to and is very compatible with parallel efforts in the civil sector to promote remedial actions at "uncontrolled" waste disposal sites. Further, the Army's program has been used as a model by the Navy and Air Force.

The key to the Army's program effectiveness lies in its centralized and flexible management structure. With a single organization fully informed and technically responsible for dealing with the Army's installation restoration problems, technological advances can be rapidly applied to corrective projects, and program priorities can be easily adjusted in response to newly discovered problems or changing regulatory agency requirements.

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THE CHALLENGES OF SITING HAZARDOUS WASTE MANAGEMENT FACILITIES

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INTRODUCTION

In this paper, an effort to site a hazardous waste disposal facility by the Gulf Coast Waste Disposal Authority—a description of what was done and the reaction to those efforts. Included is an evaluation of why the effort has encountered so many delays and a prediction of what will succeed in the task of securing a site for a hazardous waste facility.

Authority's Powers

To fully understand the total situation, an explanation of several key components is necessary. One of these is the nature of the several parties involved. The Gulf Coast Waste Disposal Authority (the Authority) was formed by an act of the Texas Legislature in 1969. At that time, the Houston Ship Channel was referred to as the most heavily polluted body of water in the world, and may actually have been in the United States' top ten most polluted.

Recognizing that the more than 150 existing governmental entities were improperly equipped to attack the broad, complex issues which had created the pollution problems in the heavily industrialized Houston/Galveston Bay area, the Texas Legislature drew heavily on the experience of the Ruhr River Valley Authority in Germany and provided the Authority with unusual powers to attack the water quality management problem of the Houston Ship Channel and Galveston Bay. Those powers include the authority to issue tax-exempt bonds; to construct, purchase and operate waste treatment facilities; to condemn land and rights-of-way; and to purchase equipment and supplies on the same tax-free basis as any other governmental entity.

Governing Board

A local unit of government, the Authority has nine directors comprising the governing board. Consisting of three members from each of the three counties comprising the Authority's area of jurisdiction, board members serve two year, overlapping terms. From each county, one member is appointed by the Governor, one by the County Commissioners and one by a consortium of the mayors of all cities within that county.

The Board sets general policy and acts in its legislative capacity to pass resolutions, issue bonds and award certain contracts. The Board also hires the General Manager, who directs the implementation of Board policy. The Authority was initially funded by a grant from the state but became financially self-sufficient in 1976. All Authority funds now come from charges for services provided. In brief, the Authority is a government that operates like a business.

Program

Early in the Authority's existence, it was determined that, with no less than three regulatory agencies active in the area, sufficient regulatory activities were being undertaken. The Authority, therefore, set its goals toward development of operational and managerial solutions to the various water quality problems of the area. Throughout its existence, the Authority has promoted a cooperative effort between the public and private sectors as the most effective approach to what are actually mutual problems.

The Authority has utilized the regional concept, joint or combined treatment facilities and operation of individual facilities, and is currently operating 26 wastewater treatment facilities and an industrial solid waste disposal facility operated for four industries in Texas City. The wastewater treatment facilities range from a 55 million gal/day combined system to a 1200 gal/day single plant. About 90 million gal/day are treated for 66 separate entities.

HAZARDOUS WASTE FACILITY

In 1977, the results of ongoing water quality management reviews indicated the need for a hazardous waste disposal facility to serve the Metropolitan Houston industrial community. The Authority staff conducted a very brief and specific purpose market survey and found the types of wastes which would need to be disposed of and their approximate quantities. During ensuing months, a concept evolved which would provide an environmentally acceptable disposal arrangement utilizing those physical facilities which were considered appropriate for the type waste produced in the general Houston area. The development of that concept included investigations of processes, physical equipment, corporate policies, financial capability, marketing practices and operational records of several separate entities.

Discussions were held with the regulatory agencies having jurisdiction over the various processes and the companies operating physical facilities, and contact was made with individuals having an interest in the operations. From these investigations, the specific processes and companies were chosen to be a part of the planned hazardous waste disposal facility. Initial contracts were then negotiated with the selected entities and the concept was finalized.

FACILITY CONCEPT

That concept called for a three party arrangement structured thusly: The Gulf Coast Waste Disposal Authority would own the land, hold the permits and be responsible for internal quality control, any waters discharged off-site and long-term site management. The incinerator contractor would construct and operate the in-

cineration process including pretreatment and resource recovery equipment for essentially organic waste materials. The chemical fixation contractor would build and operate the chemical fixation process including pretreatment, resource recovery devices for the inorganic waste materials and all ash and scrubber sludges from the incineration phase.

There are obviously many very significant items not included in that brief description of the basic concept, some of which were included in the permit application and some of which were to be incorporated in the contractually required operating plan. One key point contained in the contracts and permit application was the obligation and right of the Authority to require the shut-down of any process unit which was causing a violation of any condition of any permit.

To facilitate that control, the Authority required that all utility services (electricity, water, etc.) would be the responsibility of and under the control of the Authority. Under this arrangement, any utility could be turned off until the process malfunction was corrected. Also, the central laboratory facility would be owned and operated by the Authority, insuring no interference with the quality control responsibility of the Authority.

Waste Treatment Processes

The physical facilities to be included were two rotary kiln incinerators, one liquid combustion device, extensive pretreatment and product recovery facilities, waste materials storage, chemical fixation process equipment, a fixation product deposition area, laboratory, administration, maintenance and related facilities and utility control facilities. These were laid out to allow staged construction of a planned design of 520,000 tons/yr of waste materials.

SITE SELECTION

Having agreed on the basic relationships and physical facility, the next activity was site selection. With some input from the processors, the technical staff of the Authority set basic site criteria and then utilized an area elimination process to narrow down the possible list of sites. One site criterion was that the elevation of the site be not less than 25 ft above mean sea level. Large land areas were eliminated from further consideration by application of that criterion.

Some other criteria were proximity to population, distance to major transportation routes, general subsurface soil characteristics and proximity to the industrial community. Further application of the criteria eliminated even more land areas.

Ultimately, 20 potential sites were acceptable under the given criteria. Specific investigation of those sites was conducted, and a site was chosen as being optimum for the proposed location. The Authority felt that this site offered a bonus; the property had been used for extraction of surface deposits of sand and had large, deep, unsightly excavations remaining. Local developers and real estate agents assured the Authority that it was not economical to fill those excavations and build any structures, so the concept that the excavations ultimately would be filled with a stable, inert material and covered with clay and then native topsoil appeared to be a logical reclamation project. The Authority secured an option on the site to allow site investigation and to assure that, if a permit were authorized, the real estate would be available for purchase.

Fatal Flaw Evaluation

The Authority's next effort was what it termed a "fatal flaw" evaluation. Discussions with the state and federal regulatory agencies revealed those technical site considerations considered most significant, and the fatal flaw evaluation was conducted to insure that the site was acceptable from those technical considerations.

This site did meet the requirements set forth—the man who had extracted the sand had stopped removing sand when he had run into clay. Subsurface borings indicated that the clay had a minimum depth of 60 ft and was impervious to the extent that it met the regulatory agency requirements with ease. In effect, the site was a series of large, 35 to 45 ft deep holes whose bottoms and sides were impervious clay.

When the fatal flaw evaluation proved that the site had no apparent technical deficiencies, the investigations were extended to collect the data necessary to prepare the permit application. That required information has grown in past years to become a somewhat massive array including archaeological, terrestrial biological, aquatic biological, detailed subsurface geological and almost endless evaluation of factors relative to the site.

For example, in 1979, when this effort was underway, one of the committee advisors pointed out that one local member of the endangered species list was the Houston Toad, and the Houston Toad might be found on this site. It was determined that a prudent course of action would require an evaluation of the presence (or absence) of the Houston Toad. That evaluation is not as simple as might be expected.

To start, the Houston Toad is almost identical in physical appearance to the common toad, and even the trained eye is frequently unable to detect the differences. The toad does not occur in large numbers at any location, probably because of a natural instinct which prompts the toad to try to mate with an appropriately shaped rock or discarded apple core. But, it is this mating instinct which proved to be the key to determination of the toad's presence; the Houston Toad emits a distinctive mating call which is identifiable by a well-trained terrestrial biologist. Unfortunately, the Houston Toad only mates during a two week period in early spring and, even more unfortunately, that two week period is determined by temperature, rainfall and other less precise factors.

Consequently, to make the evaluation, one has to hire an individual with a highly-trained, especially sensitive ear to stand around in the rain (at night) for about a month to listen to frogs croak. As it turned out, from all the information gathered, there were none present. But the Houston Toad is present in other parts of the state rather remote from Houston. To further compound the Authority's frustration, the Houston Toad has now been removed from the endangered species list.

PERMITTING HURDLES

This exercise has been cited to make the point that some regulatory agency requirements, imposed by totally unwarranted legislation from that fantasy-land on the Potomac River, detract from the real intent of environmental improvement and add cost to what is already a very expensive effort—the preparation of an acceptable permit application. The country may already have reached the point where the cost of preparing a permit application, not even including the public hearings or legal expenses associated with the process, will preclude some competent entities from attempting to secure a permit for needed, technically sound disposal facilities. They simply will not have the financial resources to risk an attempt. The inevitable result is fewer facilities to dispose of larger quantities of wastes.

One of the elements in the permit application is site design, including a site layout showing relatively firm locations of all physical improvements. When the Authority's investigations and data collection had progressed to this point, it developed a public information packet and prepared a public information program complete with a variety of graphic displays and technical information.

The Authority staff initiated the public information program by meeting with a group of area environmental organization representatives including the Sierra Club, the Audubon Society, Citizen's Environmental Coalition and Houston/Galveston Toxic Substances Task Force. These representatives were present at the first program and the response was clear and direct: the need for good hazardous waste disposal was present; the high technology proposed was good; the location appeared acceptable—go to it!

This encouragement from a blue ribbon panel of knowledgeable, concerned citizens gave the Authority a sense of satisfaction and comfort which later proved unfounded, but at the time it felt that the need and technical competence of both the processes and the site would be sufficient for the project to go forward smoothly and quickly.

The Authority then met with elected officials; mayors, state representatives and state senators, congressmen from the area and the staffs of the U.S. Senators. Again, it received the go signal and comments about the obvious need for a destruction process.

A special meeting focusing on technology was held with the Public Works Department of the City of Houston, in whose corporate boundaries the site was located. Again, the comments were: the need is desperate; the technology is sound; proceed. These municipal representatives pointed out very explicitly that illicit discharges of hazardous waste materials to the municipal sewer collection system were very costly to the city and resulted in water quality problems both with the treatment processes and the collection systems.

Public Information Program

The public information program for area citizens was carried out in two concurrent efforts: Area civic organizations were contacted and arrangements made to present a program at their scheduled meetings. These civic groups included Rotary, Lions and Kiwanis clubs; professional groups such as the Association of Certified Public Accountants; engineers' associations; chambers of commerce; and various other organized groups.

The other effort involved written invitations to homeowners and businesses in the area of the site. A convenient location was arranged and evening meetings were scheduled to accommodate residents' work schedules. The program was arranged to answer all questions posed.

Over a 14 month period, 56 meetings were held at which over 1500 individuals were directly told about the plans for the project. Additionally, information packets were mailed or hand-delivered to about 500 individuals or entities. During these "public information" sessions, the first voices of disapproval were heard and they were of one theme: "It sounds great and we know it's needed, but don't put it here. Put it somewhere else."

Opposition Develops

On the morning following one evening meeting, a call was received from a real estate agent who had been in attendance the night before. He stated that he had available for sale a tract of land which he considered more suitable than the site the Authority was proposing. Over the phone, the staff determined the location of that land and informed him that it was closer to a highly populated area (the City of LaPorte) than the site selected near the City of Pasadena where he lived. His response was, "Yes, I know that, but I don't live in LaPorte." This message, "Not in My Backyard," was the only thought expressed and was coming from a very small segment of the large group with whom we had made contact.

In June, 1980, the Authority formally filed the application for permit with the regulatory agencies. The filing set in motion the normal procedures, the first of which was formal public notification of the application having been filed and setting a date for a public hearing. The hearing was held at San Jacinto College in Pasadena, near the proposed site, about 30 days after the public notice appeared. During this period, a group of residents, located approximately two miles from the site, organized themselves in opposition to the project. They called their group the Citizens Against Polluting Our Neighborhoods Environment (CAPONE). These citizens acknowledged the harsh implications of the name and stated they felt it would take forceful measures to impact the proposed facility.

Curiously, this small neighborhood group was unusually well financed, being able to commission a public relations firm to prepare a 16mm sound and color film, print three color pamphlets and retain an attorney. The Authority learned some time later that the financing for their effort was provided by an existing waste disposal company which apparently did not wish to show overt opposition. They spent in excess of $100,000 in opposing, by several methods, the permit application.

The Authority attempted to meet with the CAPONE group on several occasions but was finally informed that the opposition group did not wish to secure any facts about the project; they were determined to oppose the location. CAPONE was not alone. They were joined by another area self-styled environmental group and numerous other cities and local entities to oppose the project.

At the first official public hearing called by the regulatory agency, the attorney representing many of the opposing groups argued that he had not had sufficient time to prepare his case. He asked for and received a postponement. That was the first lesson in what is termed "legalistic delay." Over the next several months, additional lessons were learned.

City Opposition

The first real surprise came when the City of Houston announced its opposition to the site. Having met with the Public Works Department and the Mayor's office, the Authority was naive in its assumption that all was well. The Authority was unable, at that time, to learn of the basis for opposition. Now came a most frustrating period which saw legal postponements of scheduled depositions, the unusual circumstances concerning the withdrawal by the Authority's legal firm from representation in this matter and the false and misleading stories being told about various aspects of the project.

During this period, a representative of the City of Houston advised the Authority's new attorney that if the project would be relocated to an industrial area, then the City of Houston would withdraw its opposition. If the Authority persisted in its application at the chosen site, the City would utilize all avenues of opposition, including appeals to any issued permit.

In considering its position, the fact that the City maintains a large contingent of attorneys available to prepare and litigate appeals was most significant. The Authority, therefore, elected to withdraw the application and regroup for another application at a site within an industrial district.

In attempting to understand the position taken by the City of Houston with respect to the application, the Authority inquired most thoroughly of representatives of the public works department of the City of Houston, and was advised that it should contact the mayor's office for an explanation. The public works department people stated that they were directed by the mayor's office to develop a technical basis for opposition to the application. The most logical point to cite as the reason permits were not secured for the facility is the opposition of the City of Houston. The City's ability to delay ultimate completion of the project for an extended period of time would certainly cast doubts on the economic viability of the project. The Authority does not yet know precisely what triggered the obviously politically based opposition of the City.

Depth of Opposition

The preceding discussion has described the basic activities and actions relative to the aborted effort to secure a permit for a high technology hazardous waste disposal facility. The discussion did not detail the extent of the activities of those in opposition to the application. It is not that one should be unaware of those activities, but rather that it is most difficult to describe the frustration associated with attempting to deal with: blatantly false statements presented as fact; completely inaccurate stories reported by the news media as the truth; and accusations of unethical practices which never occurred. The intensity of the feelings of those in opposition can only be fully appreciated when one is on the receiving end. Words, written or spoken, are woefully inadequate as an explanation.

The fact remains that the majority of the residents in the local site area of any such project will be unalterably opposed to it. They have been educated very well by the news media on the horror stories of hazardous waste mismanagement. In many cases such as this one, local residents are contacted early by organized, well-financed opposition leaders and taught how to delay, and ultimately stifle, a project. The presentation of the technical basis and other facts about the project changed very few opinions.

A BETTER WAY

Ideally, the solution to the siting dilemma, the decision about who should have a hazardous waste management facility near them and why, lies in the formulation of fairly precise siting requirements by the regulatory agency. The "black and white" siting requirements are the technical criteria, e.g., hydrogeology, elevation. The strict application of these technical requirements would allow the applicant to follow a systematic site selection process and locate a technically superior site, thereby reducing uncertainty and economic risk. But using the "black and white" approach (adhering strictly to technical siting criteria to grant or deny a permit) would ignore the ever-present "gray area," public opinion.

Local residents' opposition cannot be ignored by the applicant and will always be part of the hearing process. As mentioned, public opposition often is not based on technical criteria. Therefore, in order to insure that public opinion is considered and the process is equitable to all parties involved, the regulatory agency is forced into the position of also formulating public participation criteria along with the technical requirements.

Now come the value judgments: How do you define an "affected party"? How much weight should be given to their arguments? And on and on. Theoretically, assuming these questions are resolved, a process defining technical siting criteria and the boundaries of public participation would be the best method for all parties concerned; costs and frustration would be minimized if the parties to a hearing knew the rules of the game going in.

Political Pressure

Nevertheless, under any arrangement, the decision making burden, whether to permit or not to permit a facility, ultimately rests with the regulatory agencies. On a practical note, the following holds true: regulatory agencies are funded by the state legislature. Elected state officials very quickly hear from the irate and most vocal opponents of a facility. They do not get hundreds of calls and letters from individuals who support a hazardous waste facility, and the irate voters' position quickly becomes the position of the elected official.

The state agency is then subjected to the hysterical voices of angry and misinformed area residents and the unique persuasive powers of legislators, whose re-election depends on satisfying the wishes and fears of area voters. Therefore, it is very doubtful that mandatory siting criteria will be issued, or could even be workable, in Texas. As is known, other states have instituted this mechanism and no regional treatment facilities have yet been permitted, much less constructed. The need for proper hazardous waste management remains.

CONCLUSIONS

Any application for a hazardous waste facility, regardless of location, will be intensely opposed. Application of well-defined siting criteria for technical requirements and public participation could reduce the uncertainty of the applicant and at least make a dent in what is now a standoff.

BID PROTESTS, CHANGE ORDERS AND CLAIMS
IN THE SUPERFUND REMEDIAL PROGRAM

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INTRODUCTION

This paper discusses bid protests, change orders and claims as they affect State-led remedial responses conducted under CERCLA. Bid protests, change orders and claims are procurement-related issues of special concern during projects managed by a State. They are, however, not unique to Superfund. They have also been of concern to the wastewater treatment construction grants program at the USEPA.

The Superfund remedial program provides long-term, permanent cleanup of the nation's abandoned hazardous waste sites. Individual site cleanups may be managed directly by either the USEPA or the affected State. If the State elects to manage the remedial response at a site, it enters into a cooperative agreement with the USEPA. The cooperative agreement is an assistance vehicle which transfers funds to the State and documents both State and USEPA responsibilities for execution of the project.

The recipient State agency then oversees the project, ensures that it meets the guidelines laid out in the cooperative agreement and manages the remedial funds provided via the cooperative agreement. At the same time, there is substantial Federal involvement under a cooperative agreement since the USEPA retains the ultimate responsibility for ensuring that provisions of the agreement are carried out.

With the increasing number of remedial actions and the award of more construction contracts by States, the number of bid protests, change orders and claims may also be increasing. If not resolved in a timely manner, these problems could seriously delay the initiation of remedial projects, affect project completion and lead to increased costs.

This paper discusses various avenues for improving the management processes dealing with bid protests, change orders and claims. The USEPA intends to develop further detailed guidance for use by Regional Offices and States patterned on the Construction Grants Program guidance. This program provides funds to municipalities for the construction of wastewater treatment plants. Construction Grants is a fully delegated program in which the municipality directly manages the project, the State monitors performance of the project and the USEPA provides and oversees the State's implementation of regulations, policy and guidance. Much of the following discussion is derived from the experience, regulations and guidance developed for the Construction Grants Program.

REGULATORY REQUIREMENTS

A State must meet the requirements of several USEPA regulations when implementing an executed cooperative agreement.

These regulations include the National Contingency Plan (40 *CFR* Part 300), The General Regulation for Assistance Programs (40 *CFR* Part 30) and the Procurement Under Assistance Agreements (40 *CFR* Part 33). Certain provisions of other regulations, as they affect the above-referenced regulations, also apply (e.g., 40 *CFR* Part 32, Debarment and Suspension).

Procurement Under Assistance Agreements are USEPA's regulations governing procurement of supplies, services and construction by assistance recipients. Under these regulations for procurement involving USEPA funds, a State may use its own procurement policies and procedures if it certifies that its system meets all the requirements of this regulation. If the State's procurement policies and procedures do not meet all the requirements of 40 *CFR* Part 33, the State must use the requirements set forth in the regulations and allow USEPA pre-award review of proposed procurement actions that will use USEPA funds (40 *CFR* Part 33 Appendix A).

Under USEPA regulations, the State may procure contracts in four ways: formal advertising, competitive negotiation, non-competitive negotiation and small purchase procurement.

For Superfund State-led remedial actions, formal advertising is the preferred method of procurement (40 *CFR* 33.910-Subpart E). For remedial planning activities, a State may, at its option, use the competitive negotiation method instead of formal advertising.

Formal advertising requires, at a minimum:
- A complete, adequate and realistic specification or purchase description of what is required
- Two or more responsible bidders who are willing and able to compete effectively for the recipient's business
- A procurement that lends itself to the award of a fixed-price contract
- The selection of the successful bidder made principally on the basis of price [40 *CFR* 33.400(b)]

Formal advertising or competitive negotiation for services maximizes use of Hazardous Response Trust Fund monies for sites nationwide. Only in rare circumstances would the USEPA approve the use of non-competitive negotiation.

Even if recipients of CERCLA cooperative agreements fully satisfy the USEPA's procurement requirements, problems may arise. The most common of these—and those that are currently of greatest concern—are bid protests, change orders and claims.

In reality, bid protests, change orders and claims are a series of interrelated issues associated with procurement. The Superfund Program emphasizes the importance of preventing bid protests and claims, to the extent possible, by the up-front preparation of quality solicitations and also stresses the need to effect meritorious change orders through good project management.

BID PROTESTS

Bid protests are written complaints filed by parties with a direct financial interest affected by the State's procurement action. Since complaints typically concern the solicitation (e.g., content or wording of or deficiencies in specifications) or the actual award of contracts, they are of concern to both the USEPA and the State. Bid protests may significantly delay the initiation of a remedial project. Thus, it is vital to avoid their filing when possible.

A protestor may file an appeal with the USEPA after the State's bid protest has been made and all available administrative remedies at the State level have been exhausted. The protestor may file an appeal only when he feels his financial interest has been adversely affected. The administrative process for the rapid resolution of bid protest appeals by the USEPA are contained in the regulations 40 *CFR* 33.1105-1145. Limitations regarding timing and content of the appeals are also defined.

A State is required to develop procedures to promptly consider bid protests (40 *CFR* 33.1110). Generally, a State defers award of the contract and delays initiation of remedial activities pending a determination on the protest. Upon resolution of the bid protest by the State, all affected parties have a limited period of time to file a protest appeal with the USEPA.

Upon receipt of a protest appeal, the USEPA will request the State to defer award of the contract. Although a State is not required to defer the award, it bears the risk that the costs of the contract may not be allowable for Federal funding if the protest appeal is upheld. If a protestor does not agree to a request from the State for a reasonable extension of the bid or bid bond period while the protest or appeal is pending, the State or the USEPA can summarily dismiss the protest or appeal.

The USEPA's review of protest appeals is limited to issues arising under the provisions of 40 *CFR* Part 33 and alleged violations of State or local law or ordinances when the USEPA has determined that there is an overriding Federal requirement. A subcontractor may only file a protest appeal for certain issues related to the award of that subcontract by a contractor (40 *CFR* 33.1115 and 33.295).

The USEPA reviews the record considered by the State and any additional information regarding the basis of the appeal and renders a final decision. The USEPA's decision regarding a protest appeal is final and may not be appealed by the protester or the State. If a State does not comply with the USEPA's determination, the USEPA can take action against the State under 40 *CFR* Part 30 (40 *CFR* 33.1145).

A State can minimize or avoid protests by developing high quality, unambiguous bid documents with a clear and accurate description of the technical requirements for any necessary materials, products or services. In developing specifications for the remedial projects, a State should incorporate a clear and accurate description of the technical requirements for any necessary materials, products or services and the required performance schedule.

Through arrangements with the Corps of Engineers (COE), the USEPA can provide a State with a mechanism to do biddability/constructability reviews at the State's request. These reviews will be conducted concurrently with any internal review the State may choose to conduct and will not result in delays to the procurement process. Because the COE performs remedial activities for Federal-led remedial sites, their technical expertise should prove extremely useful to a State. The USEPA may also require as a condition of the cooperative agreement, the COE to perform such a review for the State for projects which are, in the USEPA's opinion, technically complex or have severe time constraints.

The USEPA currently is exploring the possibility of funding, as a portion of cooperative agreements with a State, the costs associated with the State securing independent services to perform biddability/constructability reviews.

Technical assistance provided by the COE or the use of services of an independent reviewer could contribute to an effective bid protests prevention program implemented by any State. In the case of Superfund, expertise and experience is limited and bid protests and subsequent protest appeals may hamper the timely implementation of remedial activities.

CHANGE ORDERS

A change order is a written order issued by the State or its designated agent to its contractor authorizing an addition to, deletion from or revision of a contract, usually initiated at a contractor's request. Change orders are issued after execution of the contract. The State may also direct changes in the contracts. Proper management of change orders is a key element in avoiding increased costs as well as contractor claims which are discussed in the next section of this paper.

Administrative requirements for management of change orders including timing, form and provisions for contract adjustment appear in the model subagreement clauses of 40 *CFR* Part 33.1030. These clauses delineate requirements for construction contracts [clause 3(a)], contracts for services [clause 3(b)] and contracts for supplies [clause 3(c)]. In addition, a clause exists to describe requirements for changes resulting from differing site conditions (clause 4).

Change order management practices which avoid significant increases in contract costs are essential to both the State and the USEPA. States may choose to manage contracts directly or secure the services of a private construction oversight firm. In the Superfund program, the design engineering firm frequently provides the construction oversight services. In addition, the USEPA will consider funding services of a firm specializing in change order management as part of the cooperative agreement with the State.

Change orders are often generated by the following conditions:
- Differing site conditions
- Errors and omissions in plans and specifications
- Changes instituted by regulatory agencies
- Design changes
- Overruns/underruns in quantities
- Changes in time of completion

In the course of remedial action, the USEPA anticipates there will be requests for change orders. Cooperative agreements with the States routinely provide a contingency fund for the construction contract for such change orders. This fund is often in the 5 to 15% range. States are prohibited from using these funds, however, without obtaining USEPA concurrence.

Change orders may also be encountered during remedial planning phases of work at a particular site. States may rebudget existing contract funds in the cooperative agreement to pay for necessary changes. However, if change order costs exceed the funds in the existing cooperative agreement, the State must request additional funds from the USEPA. State approval of a change order does not obligate the USEPA to increase the amount (40 *CFR* 30.702) of a cooperative agreement.

Administrative and procedural requirements for State management of change orders are discussed in the model subagreement clauses (40 *CFR* 33.1030). In addition, all negotiated change orders exceeding $10,000 must have a State-conducted cost analysis.

If a change is deemed to be substantial, the cooperative agreement must be formally amended [40 *CFR* 30.700(d)]. Change orders requiring an amendment to the cooperative agreement include:
- Significantly changed conditions at the site
- Changes substantially increasing or decreasing the funds needed to complete the project
- Significant delay or acceleration of the project schedule
- Changes to the approved remedy

The USEPA feels, however, that certain additional tools will aid a State in change order management. The USEPA will ask the State to conduct an administrative and technical analysis of all individual change orders exceeding $100,000. This analysis should consist of a review of the effects of such a change on the existing scope of work.

In the case of remedial action, the analysis must also take into account the Record of Decision (ROD) selecting the most cost-effective remedy. Should the change order cause the USEPA to re-examine the selection of the remedy, the ROD may require amendment prior to USEPA making funds available for the change order.

Similarly, the USEPA will also require such an analysis from the State when the aggregate costs of change orders exceed 10% of the contract.

In this way, USEPA will provide a State with the opportunity to assess the effect of change orders on the remedial activities. The State must promptly consider all proposed change orders and issue those that are meritorious. This process includes an investigation of contractor reports of differing site conditions to see if they will require a change order. These activities are within the scope of the contract management tasks and are included as a standard task in most cooperative agreements.

CLAIMS

Claims consist of requests by the State's contractor for changes (e.g., additional time and/or costs) which have been originally rejected by the State. These claims, obviously are of significant concern to both the USEPA and the State.

The State is responsible for the satisfactory completion of the contract for the work outlined in the cooperative agreement (40 CFR 33.210). However, the State may still encounter the issue of claims when the project has been conducted in a thoroughly satisfactory manner.

The development of a claims policy and the procedures for administering this policy are of vital concern to the Superfund program. The costs of claims are subject to budgeting considerations and must be analyzed in light of funding priorities for all Superfund activities.

Claims may be encountered by a State both in contracts for services and for construction. Many claims that States have encountered result from:
•Defects in plans or specifications
•Differing site conditions
•Inadequate construction inspection and management
•Failure to promptly and fairly address contractor grievances, requests for time extensions or other problems
•Failure to enforce contract provisions on scheduling and completion time
•Failure to negotiate time extensions and/or delay costs, if any, associated with change orders
•Failure to mitigate effects of delay
•Unusually severe weather conditions
•Strikes
•Acts of God

Consequently, good project management practices have been identified which could reduce the number of change orders and the occurrence of claims for any type of contract in the State-led remedial program. Some elements of good management include:
•Recognizing the importance of scheduling as a key management tool by specifying that the contractor provide a realistic and adequate schedule commensurate with the complexity of the project. Enforcing the schedule provisions and requiring periodic updating to show the adjusted project progress and completion date are equally important.
•Maintaining a full and completely documented record of all aspects of the work (such as photographs) and a daily log of work progress, personnel and equipment on site.
•Demonstrating a knowledge and understanding of common sources of disputes or situations likely to result in claims during construction and exercising effective techniques to avoid such situations.
•Exercising effective management of change orders, resolving all costs and any necessary contract time extensions associated with each change order as the change order is executed.

•Providing timely responses to contractor requests for direction, clarification and adjustment.
•Instituting measures to ensure accurate and complete plans and specifications (e.g., biddability/constructability reviews) and holding pre-bid conferences.

The USEPA can, by amending a State's cooperative agreement, fund a portion of the costs that a State incurs in analyzing the merits of claims as well as the costs associated with negotiating a settlement or defending itself against claims. However, a State must request such claims management funding from the USEPA in advance of resolving the claims. The USEPA then reviews the schedule, budget and scope of work required for claims management by the State and assesses whether the claims resulted from poor management or other factors. This determination is the basis for the USEPA's decision to fund claims management costs.

After the State receives the award of the cooperative agreement amendment, the process of claims management or defense against claims may proceed. The following suggested actions will aid the State in resolving claims:
•Take immediate steps to mitigate further costs being incurred by the contractor, or any other party, due to the claims issue
•Perform a timely, complete and thorough review of the issues raised by the claims to determine the degree of merit that each issue may have
•Negotiate with the contractor on the issues in a good faith attempt to resolve each issue
•Make a renewed effort to negotiate a fair and reasonable settlement of the meritorious issues and a reduction or elimination of the issues found to be without merit
•Maintain a fully and completely documented record of the negotiation process used to resolve the claim
•Provide a high degree of attention to dispute resolution [40 CFR 33.1030 (clause 7)]

During the claim(s) resolution process, the State may choose to consult with the USEPA. Because the State is responsible for all meritorious contractor claims, the USEPA must carefully evaluate the extent of the USEPA's interest in awarding the State the costs of claims.

The State may choose to submit a cooperative agreement amendment request to the USEPA before a final settlement takes place. This will enable the State to determine the USEPA's evaluation of the extent to which the USEPA may award costs allocable and allowable to the project prior to reaching a settlement with the contractor. Should the State negotiate a settlement, the USEPA must determine whether the costs associated with the claim are (1) eligible, allocable and allowable (40 CFR 30.200); (2) within the scope of work agreed upon; (3) consistent with the record of decision; or (4) the result of differing on-site conditions which caused imminent and substantial endangerment requiring immediate attention.

Claims that alter the cost-effectiveness analysis and selection of the remedy may require a supplemental ROD. Approval of such a ROD must precede award of funds for a cooperative agreement amendment.

When funds become available, the USEPA may choose to award to the State, via an amendment to the cooperative agreement, the costs of the claim(s) determined to be allowable. Thus, the USEPA has made claims prevention, claims management and claims resolution an essential element of managing the costs of cleanup at Superfund sites.

CONCLUSIONS

The effective management of procurement and procurement related issues is a major segment of the State-led remedial program. Issues resulting from bid protests, change orders and claims have a direct effect on the USEPA, the State and the contractor.

A State can minimize or avoid protests with high quality, unambiguous bid documents that contain a clear and accurate description of the technical requirements for any necessary materials,

products or services. To ensure that Superfund remedial project requirements are adequately explained and schedules clearly delineated, the USEPA, via an interagency agreement, is offering the assistance of the U.S. Army Corps of Engineers to perform biddability/constructability reviews for a State. The USEPA is also considering providing funds to a State to secure independent third party services to conduct biddability/constructability reviews. In certain instances, because of technical complexity or scheduling concerns, the USEPA may require a State to submit bid documents for COE review.

With regard to change orders, the USEPA emphasizes the importance of change order management. Good change order management will provide a mechanism to control costs of a project and a mechanism to avoid the filing of claims.

Major checkpoints in the process will include: obtaining USEPA approval to draw down construction contingency funds; technical review and concurrence on the State's analyses of change orders in excess of $100,000; and notification and provision of an analysis to the USEPA of the effect of change orders when change orders exceed 10% of the contractual funds. These checkpoints provide the USEPA with the ability to monitor project progress and costs and provide the States with funds and management tools to effectively pursue the objectives of the remedial project.

Claims remain another area of concern to the Superfund program. The USEPA proposes to provide funding and technical support to a State to prevent, manage and resolve claims via the cooperative agreement process. As mentioned previously, effective change order management is a vital element in the prevention of claims. By funding a State's claims management costs and providing Agency expertise, the USEPA hopes to furnish a State with an enhanced capacity to resolve claims and to defend against claims.

The USEPA will consider funding claims allowable to the project in an amendment to the existing cooperative agreement. In this way, a State will be recompensed for expenditures of time and effort in good project management.

The USEPA will provide more detailed information to States via an addendum to the *State Participation in the Superfund Remedial Program* manual in the near future. The USEPA will also consider additional methods for improving the procurement process and change order management and for minimizing bid protests, protest appeals and claims. The USEPA will also determine whether regulatory changes or additions are necessary based on the effects of implementing the above-detailed initiatives.

The USEPA hopes implementation of these measures will streamline projects, prevent some cost increases and allow projects to proceed to completion within the scheduled time frame.

S-AREA: NEGOTIATED REMEDIAL PROGRAM FOR THE NIAGARA FRONTIER'S MOST COMPLEX SITE

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INTRODUCTION

In 1978, a chemical sludge was discovered in the intake structures of the Niagara Falls, New York, drinking water treatment plant. Further investigation revealed that the source of these contaminants was an adjacent inactive landfill, known as S-Area (Fig. 1). Owned by the Occidental Chemical Corporation, formerly the Hooker Chemicals and Plastics Corporation, the site was also contaminating the Niagara River, an international body of water. In this paper, the authors discuss the history of the case and present the most important components of a proposed settlement agreement that has been submitted to the Court.

CASE HISTORY

To remedy the problems created by S-Area, the United States Department of Justice, acting on behalf of the USEPA, filed a lawsuit against Hooker on Dec. 20, 1979. This civil action sought injunctive relief from the imminent and substantial endangerment that arose from the contaminants that had escaped and were escaping from the site.[1, 2] This action, one of four taken against Hooker in Niagara Falls, was one of the first in the country regarding a hazardous waste site. The State of New York (State) joined the action and became a co-plaintiff on Nov. 18, 1980. Earlier that same year, the City of Niagara was named as a co-defendant.

On Jan. 10, 1984, after more than three years of negotiations, the parties filed a proposed stipulation and judgment,[3] to resolve the litigation, with the U.S. District Court for the Western District of New York. Thousands of hours of work went into the negotiations; the USEPA spent more than $2,000,000 in consultant fees.[4] More than 100 negotiating sessions were held.

Several groups sought to intervene in the case. Although local environmental groups, with both American and Canadian members, were denied such status, the Court did grant intervenor status to the Canadian Province of Ontario. (The environmental groups have appealed the Court's decision.) A diplomatic note was sent to the United States by Canada to express its criticisms of the agreement. Technical meetings were held with representatives of both the Canadian federal and provincial governments. Through the Niagara Frontier Agenda, a bilateral consultative group, frequent discussions of the case were held with the Canadians.

An evidentiary hearing (similar to a trial was held in Court from Apr. 30 to May 3, 1984. At this hearing, the terms of the agreement were presented to the Court and Ontario's arguments were heard. As of Sept. 1, 1984, the Court's decision was still pending. Pursuant to the agreement, official implementation activities would begin after a required 60-day appeal period which would follow a decision approving the agreement.

SITE HISTORY

The site was used by Hooker as a dump from 1947 until 1961.[5] Built on land that was partially reclaimed from the Niagara River, the site lies at the southeast corner of Hooker's Buffalo Avenue plant (Figs. 1 and 2). On it are situated two settling lagoons utilized in a nearby process. Eastward, directly across 53rd Street, is the Niagara Falls drinking water treatment plant: a 64,000,000 gal/day facility with water treatment units known as plant A (ca. 1953) and plant B (ca. 1911).

Beginning in 1947, Hooker dumped approximately 63,100 tons of inorganic and organic chemicals at S-Area (see Table 1);[6, 7] the predominant compounds were chlorinated hydrocarbons. These solid or liquid chemicals were deposited in barrels, in other containers (including at least one railroad tank car) or in bulk. Other deposited materials included construction wastes.

SETTLEMENT AGREEMENT OVERVIEW

The agreement presents a program to remedy the problems. Included are elements of both a remedial investigation and a remedial action program. While general guidance is given, specific engineering details will be developed only after more extensive field data are gathered. Thus, the agreement is dynamic.

The settlement agreement outlines activities that may require 4 to 8 years or more for complete construction. Thereafter, maintenance and monitoring activities will continue until the 35th and 38th anniversaries, respectively, of the Court's approval of the agreement. If the site continues to endanger the public health and welfare and the environment, the terms of the agreement will be extended until the endangerment exists no longer. Thus, the agreement is highly protective.

The settlement agreement was patterned on the work that the Federal and State governments performed in another Hooker case in Niagara Falls—the Hyde Park landfill. The additional experience at S-Area and its settlement agreement document have already been used by USEPA and the State in negotiations with Hooker and the Olin Corporation in the 102nd Street case in Niagara Falls. Thus, the document is useful elsewhere.

Finally, the settlement agreement is part of a comprehensive remedial effort at Hooker's Buffalo Avenue plant. The State has initiated a lawsuit against Hooker regarding multiple hazardous waste sites there [*State of New York & Henry Williams v. Occidental Chemicals Corp.,* Civ. Act No. 83-1393 (W.D.N.Y., Dec. 8, 1983)]. All parties recognize that remedies from these actions should be designed and operated compatibly, if possible.[8] Thus, the document both affects and is affected by other actions.

Note: The views expressed herein are those of the authors and do not necessarily represent those of the USEPA of the State of New York.
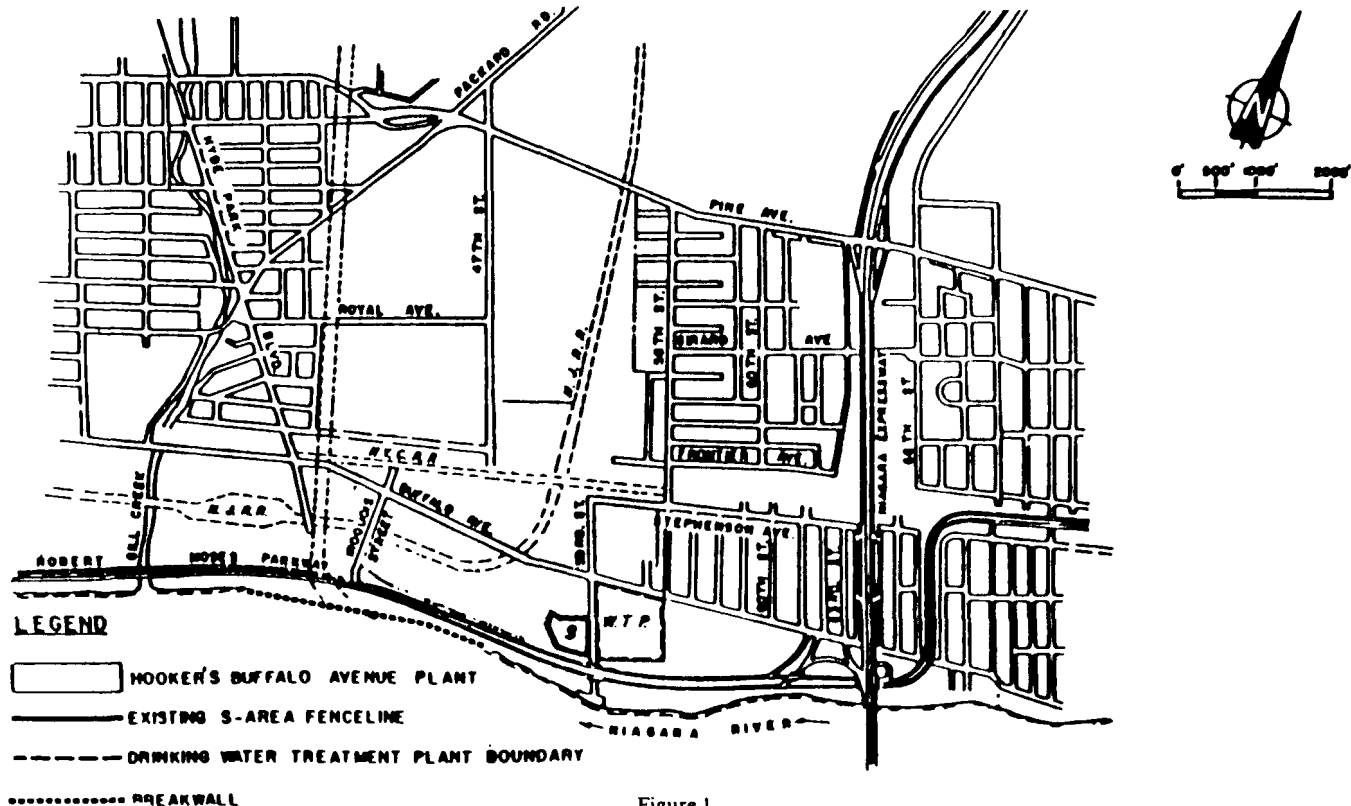
Figure 1
Geographical Location of S-Area Landfill Site

Table 1
S-Area Chemical Inventory

Waste Category	Physical State	Estimated Quantity (Tons)	Container
Organic Phosporous Compounds	L, S	200	D, B
Miscellaneous Acid Chlorides	L, S	400	D, B
Phenol Tars (Including chloro-benzenes)	L	800	B
Thionyl Chloride	L	4,100	D
HET Acid (Chlorendic Acid)	L, S	500	D, B
Miscellaneous Chlor-inations	L, S	400	D, B
Dodecyl Mercaptans	L, S	600	D
Trichlorophenol	L, S	200	D
Benzoyl Chloride	L, S	3,300	D, B
Liquid Disulfides/ chlorotoluenes	L, S	2,200	D, B
Metal Chlorides	S	900	D
Hexachlorocyclopenta-diene	L, S	17,400	D, B
Chlorobenzenes	L, S	19,900	D, B
Benzyl Chlorides	L, S	1,600	D, B
Thiodan (Endosulfan)	L, S	700	D, B
Sulfides	S	4,200	D
Miscellaneous (10% of above)		5,700	
TOTAL		63,100	

Legend: L = Liquid, S = Solid, D = Drummed, B = Bulk
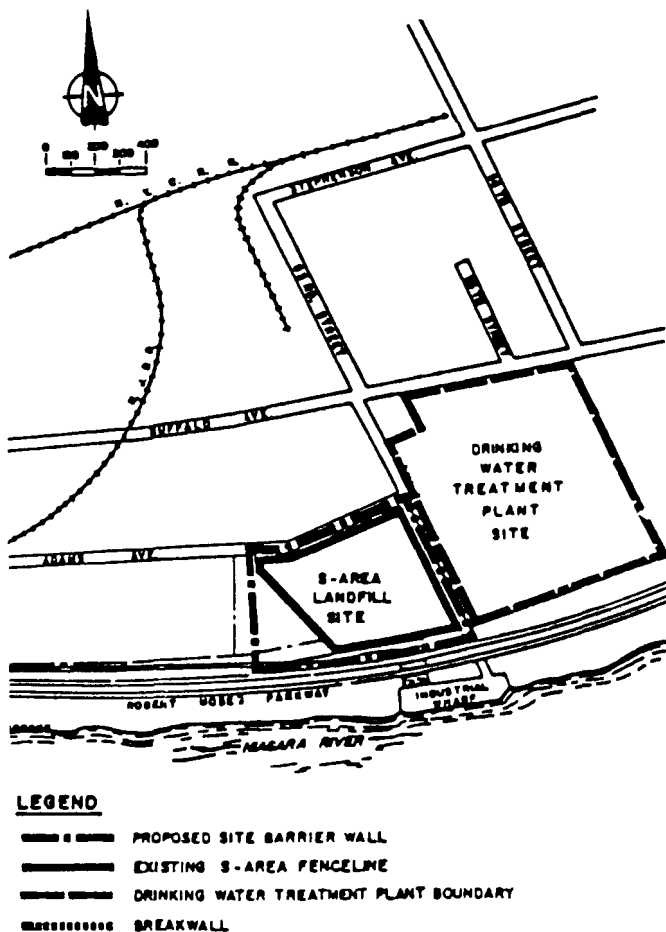
Figure 2
S-Area/Water Treatment Plant Site

IMPORTANT/INNOVATIVE FEATURES
OF THE SETTLEMENT AGREEMENT

First, the proposed agreement[9] is flexible. Any specified remedies and monitoring systems can be modified, based upon the evaluation of actual field data. The agreement requires adequate data before any final decisions can be made regarding any remedial measure.

Contained in the agreement is a unique mechanism which combines flexibility with the requirement for adequate data: requisite medical technology (RRT). Through a phased approach, Hooker will gather and evaluate data to determine more fully the nature and extent of off-site contamination. If those data are inadequate, Hooker must gather more data. More importantly, Hooker must initiate an RRT study to find a remedy for an identified problem.

The RRT considers human endangerment as well as the practicability of implementation. Hooker is required to consider all available information in assessing off-site contamination as well as any remedy. Thus, the RRT process uses a fully-developed scientific data base to find and to designate appropriate solutions, if any. Prototypical remedies can be installed to evaluate such remedies by gathering more data.

Computer models will be used innovatively through the agreement. Four groundwater flow models were used during the negotiations to evaluate the impact of the proposed remedies. The USEPA modified the USGS (Pinder) model and then verified those predictions with another model that was developed. Such modelling will be used, in the program, to insure the effectiveness of these remedies.

Another way in which computer models were used, and will be used, regards the innovative upward hydraulic gradient concept. A two-phase transport model,[10] suggested by the USEPA (Pinder) and developed by Hooker, will be used to verify that the required upward gradient is being obtained.

Another feature is the extensive landfill monitoring program that will be required. Its components—hydraulic, chemical and tracer systems—will provide redundant protection by monitoring the effectiveness of the remedies.

The environmental health and safety plan[11] is another important feature. It will protect on-site workers as well as off-site workers (Hooker's and others) and nearby residents.

REMEDIAL PROGRAM ELEMENTS

To remedy the problems caused by S-Area and to protect the users of the City's drinking water supply, the proposed settlement agreement contains five main activities:[12]

•Containment and, to the maximum extent possible, collection of the deposited hazardous materials

•Employing the RRT concept that will be used to develop remedies for chemicals that have migrated off-site

•Correction of damages to and cleaning of the Niagara Falls drinking water treatment plant, including the property

•Long-term monitoring of the landfill and treatment plant containment and collection systems and the finished drinking water quality

•Long-term maintenance of all remedies

Another critical component of the agreement is a fiscal guarantee from Hooker that the necessary funds will be available to meet its obligations to fulfill the terms of the agreement.[13] That guarantee, the previously-mentioned environmental health and safety plan and the five main activities comprise the terms of the proposed agreement.

The following discussion of the major program elements is divided into the two functional elements: the S-Area landfill, itself, and the Niagara Falls drinking water treatment plant.

THE LANDFILL CONTAINMENT PROGRAM

According to the settlement agreement, the purpose of the containment program[14] is "...to identify and where required, using requisite remedial technology, to contain or collect chemicals which have migrated into soils, bedrock, sediment, surface runoff waters, groundwater, and air from the landfill site, when detected at levels at or above specific survey threshholds."[15]

Site Geology and Hydrogeology

The site is composed generally of geologic materials that are categorized as the overburden and the bedrock.[16] Overlying the bedrock, the overburden consists of two layers: the uppermost unconsolidated layer composed of sand, silt, clay and fill (e.g., cinders, stone, slag, wood, dirt, etc.); and the lowermost glacially-derived clay/till layer. The uppermost layer's thickness is approximately 30 to 35 ft; the lowermost's ranges from approximately 0 to 20 ft.

The significant bedrock units include the uppermost Lockport dolomite formation and the underlying Rochester shale formation. The topmost 15 ft of the Lockport formation are highly fractured and serve as a pathway for chemical migration. The bedding planes in both formations slope gently (30 ft/mile) to the south, toward Canada.

The upper zones of the overburden and the bedrock are the most permeable. There is at least one discontinuity (or hole) in the clay/till layer through which chemicals have migrated into the bedrock.

Two major lateral flow zones comprise the groundwater flow zones. The flow in the overburden is generally from the north to the south, toward the Niagara River (Fig. 3). In the bedrock, the flow is generally in the opposite direction (Fig. 4).

Field Investigations

The proposed settlement agreement requires initial surveys and studies.[17, 18] According to a predetermined logic, wells would be drilled in the overburden, the bedrock and the utility beddings in and around the known disposal area. Sampling and analyses will then be made for both general and specific indicator chemicals. The resulting data will be analyzed to assess the spatial migration of chemicals in the geological zones.

LEGEND

——— — —— EXISTING S-AREA FENCELINE

—— —— —— DRINKING WATER TREATMENT PLANT BOUNDARY
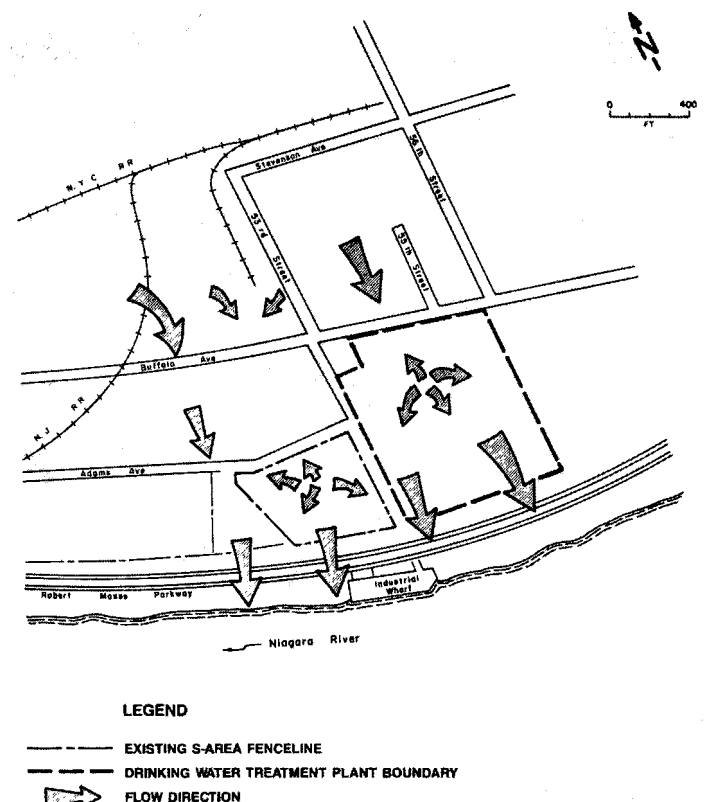
▷ FLOW DIRECTION

Figure 3
Generalized Flow Directions in the Overburden Water Table at the S-Area/
Water Treatment Plant Site
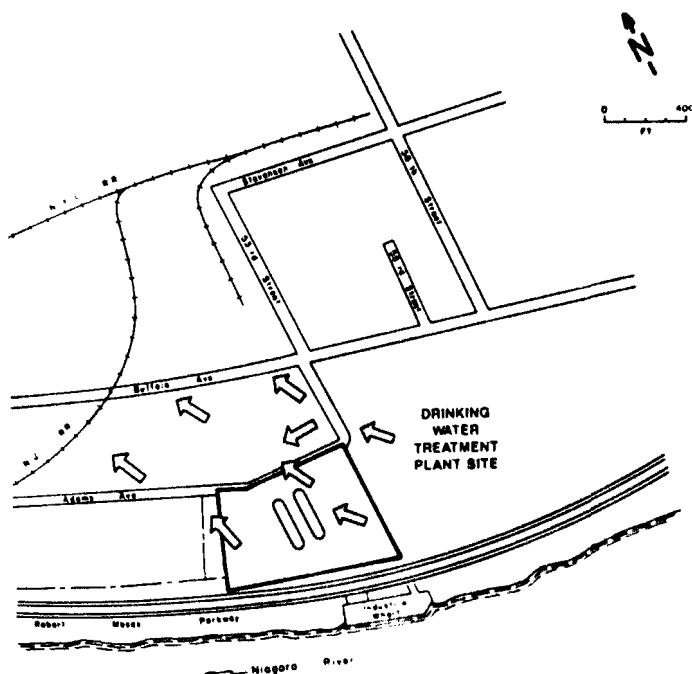
Figure 4
Generalized Flow Directions in the Bedrock Aquifer at the S-Area/
Water Treatment Plant Site

Table 2
Average Composition of S-Area Non-Aqueous Phase Liquid

Compound	Average Composition (% of Total %)	Water Solubility (milligram/liter)
Tetrachlorobenzenes*	37.2	0.4
Trichlorobenzenes*	15.5	30.0
Tetrachloroethylene	7.5	200.0
Hexachlorocyclopentadiene	6.5	2.0
Octachlorocyclopentene*	10.0	<0.1
Pentachlorobenzene	6.4	<1.0
Carbon Tetrachloride	1.5	800.0
Toluene	1.8	500.0
Hexachlorobutadiene*	3.6	2.0
Monochlorobenzene*	3.7	500.0
Hexachlorobenzene*	2.8	0.02
Monochlorotoluenes	1.2	20.0
Dichlorobenzenes	0.9	123.0
Hexachloroethane	0.5	50.0
Trichloroethylene	0.3	1,100.0
TOTAL PERCENT	99.4	

% S-Area Indicators   72.8

Legend: *Chemicals that are used as S-Area indicators. Data taken from Reference 20.

These surveys and studies divide the contamination into the two distinct phases, aqueous and non-aqueous, discovered in previous investigations. The aqueous phase comprises those soluble chemicals which flow with the groundwater. The non-aqueous phase liquid ("NAPL") is that mixture of relatively insoluble chemicals which is more dense than water and which can move independently of the hydrogeologic conditions[9] (Table 2).

Concurrent with chemical sampling, piezometric elevations will be determined, and the geological and hydrogeological characteristics of soil and rock will be examined. In particular, special consideration will be given to the geological characteristics of the industrial intake-pipe trench. This trench, which contains large-diameter pipes (up to 72 in.) that transmit river water to the chemical plants near the river, crosses the S-Area boundary at two locations (Fig. 5).

This survey and study program will describe the three classes of parameters influencing remedial activities at this or any other inactive hazardous waste site:
• The levels of chemistry present
• The pathways for migration
• The dynamic influences
Full description of these elements will permit both the consideration and the design of specific remedies.

Selected Remedial Concepts

The following general remedies were considered: excavation and disposal; excavation, destruction and disposal; in situ destruction; or various containment schemes.

The first three concepts were examined extensively during negotiations. As an initial remedy at this site, excavation was deemed infeasible for several reasons. The mere quantity (up to 10⁶ bank yd³) of soil and bedrock requires immense resources for either final disposition (including sites), thermal destruction capabilities or both. Large volumes of contaminated groundwater, requiring treatment and disposal, will be generated. The risk to both workers and the community-at-large would be unacceptable.

In situ destruction (e.g., incineration, chemical or biological techniques, etc.) was not commercially available to accommodate this type and quantity of waste. Thus, it was decided to develop a

Figure 5
Location of Barrier Walls and Plugs

containment system composed of a barrier-wall (with hydraulic controls), a clay (bottom) confining layer and surficial capping.

Envelopment or encapsulation of contamination at inactive hazardous waste sites is fairly common. At S-Area, however, in order to develop a practicable and reliable containment system, selecting this remedy required rigorous planning, modelling and evaluation. Two site-specific concerns adding to the complex nature of this landfill are the presence of NAPL and the absence of a continuous, low-permeability, confining stratum. These two concerns were addressed by using another site-specific hydrogeologic condition advantageously: the bedrock aquifer, which is influenced by the adjacent Niagara River, will be used as a barrier to the downward flow of chemicals from the site (Fig. 6).

Containment System Components

The containment system[22] will consist of the following:
- Barrier walls
- Drain-tile collection system
- Barrier plugs
- Surficial capping
- Clay (bottom) confining layer
- Upward (hydraulic) gradient

These are fully described in the proposed settlement agreement.

The agreement provides for a 2-ft barrier wall that circumscribes the site. This wall, having a maximum permeability of 1×10^{-6} cm/sec, extends from the land surface down to a depth of 1 ft into the clay layer. While this barrier will impede the lateral flow of chemicals from the site, its primary purpose will be to significantly retard, and thus reduce, the flow of groundwater into the containment system. This flow reduction is a major consideration in the overall containment scheme.

A drain-tile collection system will be used with the barrier to "maximize the containment (and collection) of aqueous and non-aqueous phase liquids located within the site barrier wall."[23] The collected liquids will be adequately treated and subsequently discharged.

Where the industrial intake-pipe trench crosses the site boundaries (Fig. 5), plugs will be emplaced to reduce the trench's ability to act as a pathway for chemical migration. Low permeability (1×10^{-6} cm/sec) grout will be used. These plugs will extend downward to a depth below the bedding material in the trench.

Complete surficial capping of sites is another standard technique modified for use at S-Area. There are two actively-used process-waste settling lagoons situated on S-Area (Fig. 5); their continued operation atop the contained landfill will not be excluded. To eliminate their influence upon the landfill, these lagoons, if operated, will be reconstructed with a protective system consisting of a synthetic liner, a coarse-sand layer, a drain-tile collection system and a clay liner. Thus, even if the lagoons are operated, there will be the equivalent of complete surficial capping. Once installed, the cap will greatly retard the influence of surficial water on the landfill.

Basic to most containment systems is a barrier which prohibits downward flow of chemicals. Geologic conditions usually provide such a barrier. As mentioned previously, a low-permeability clay layer underlies most of S-Area; in at least one location, though, this stratum is absent. Required testing will define this area of discontinuity as well as the integrity of the existing clay (bottom) confining layer. Where the clay exists in sufficient depth, its impermeability will act to retard chemical flow. Total downward vertical migration through the discontinuity will be prevented, nonetheless, as will be seen.
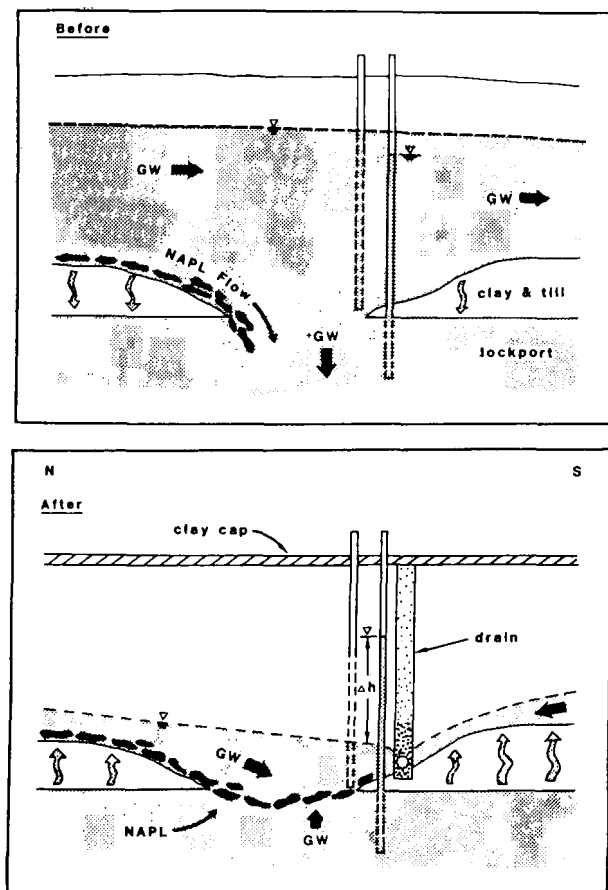
Figure 6
Impacts of Drains in Causing Inward and Upward Groundwater Flow.[21]
(The water levels are lower in wells inside the landfill than in those wells outside of the landfill, and below the clay/till layer.)
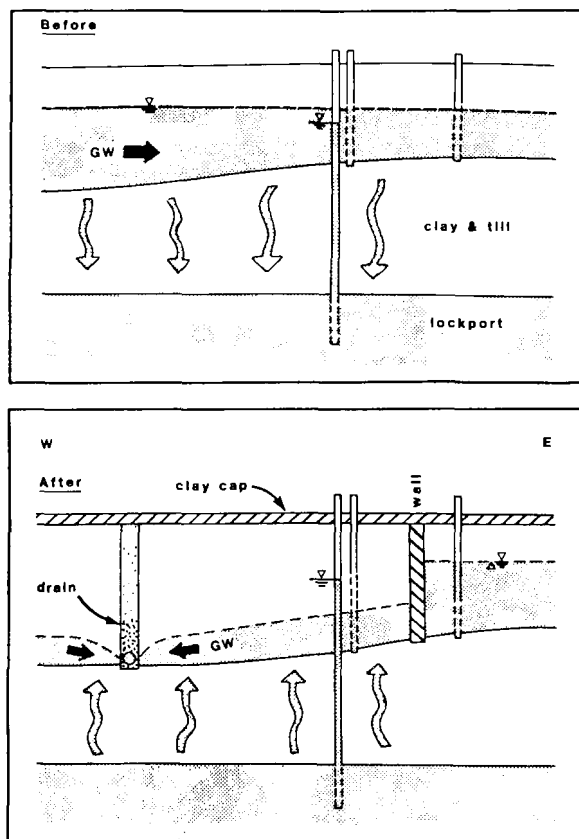
Figure 7
Concepts of the Upward Hydraulic Gradient.[24]
(The water level difference between wells in the overburden and bedrock must be large enough to cause upward flow of NAPL.)

Another hydrogeological barrier used to contain chemicals is the difference in hydraulic pressure between aquifers. In S-Area, at or near the discontinuity, an upward gradient will be created through the drawdown of the drain-tile collection system (Figs. 6 and 7). Installation of sufficient drain tiles will lower the overburden's groundwater elevations. This action will cause the upward pressure exerted by the bedrock aquifer to become greater than that pressure in the overburden. Thus, the contaminants will be either suspended or moved upward toward the drain tiles (the more likely occurrence). While the chemicals will be collected, the purpose of the upward gradient will not be to flush or eventually remove all chemicals from the site; its purpose will be to reverse the flow of groundwater, back into the site, thus preventing the downward migration of chemicals.

The upward hydraulic gradient concept is essential to the overall containment of both aqueous and non-aqueous phase chemicals. As mentioned earlier, the feasibility of this upward gradient has been demonstrated through both transport and flow modelling performed by Hooker, by the USEPA and by the State. Two of these models will be used to verify the performance of this innovative remedial concept.

Off-Site Remedial Concepts

In addition to the containment of chemicals at the site, the proposed agreement provides remedies regarding three other concerns at or near S-Area: an adjacent disposal site just north of S-Area (the Northern site); contamination that has migrated off-site in the overburden, and contamination that has migrated off-site in the bedrock. A Northern Containment System similar to S-Area's would be constructed.[25] Even though the thickness of the clay layer is expected to suffice for vertical containment, this assumption will be verified by testing.

off-site migration into the bedrock and into various strata outside the S-Area's bounds will be studied to develop remedies.[26] These studies, comprising a program similar to a remedial investigation, will determine an RRT. If a remedy is warranted, based upon the findings of the studies, either the parties will agree to its terms or it will be subject to a Court-determination. Thus, ancillary issues can be resolved without delaying installation of major components of the site containment system. Such containment necessarily precedes some major remedial activities at the water treatment plant.

Implementation

The containment system will be a part of the remedy at S-Area. Installation of that system will be predicated on specific designs based upon gathered field data. The plans, specifications and protocols will be submitted for USEPA and State approval prior to any construction. After such approval, the governments will oversee the installation of the remedies. At the end of 38 years, if an endangerment remains, these systems will continue to operate until that endangerment ceases.

Maintenance and Monitoring

Hooker must maintain the installed remedies for the term of the agreement.[27] In addition to hydraulic monitoring, both chemical and tracer monitoring systems will be required. After conducting field tests, Hooker will design these systems. Guidance has been given regarding the number of wells and the approximate locations for the final systems. If, however, Hooker demonstrates the infeasibility of such monitoring, it will not be required: alternatives will be required. If the systems are installed, many years of data will be reviewed to determine whether the systems are providing the required type and quality of data. All three systems monitor the long-term effectiveness of the containment systems.[28]

DRINKING WATER TREATMENT PLANT REMEDIAL PROGRAM[29]

The remedies will be designed to protect the public water supply against past or potential future contamination from S-Area.

Hooker will install or undertake them "without altering existing structures, and without adversely affecting the City's ability to adequately process and supply finished water for distribution."[30] These remedies are divided generally into three major components:[31]

• Measures that eliminate the potential for chemicals to infiltrate the treatment plant structures and piping
• Measures that prevent contamination from entering the bedrock intake system through its floors or walls
• Measures that remove past contamination from the treatment plant structures and piping

These measures will be augmented by both maintenance and monitoring programs.[27, 32] There will be a separate maintenance agreement between Hooker and the City. Hooker will monitor the collection systems to ensure both free-flow conditions and proper operation. Groundwater elevations around the water-bearing structures will also be monitored. Finally, the plan requires stringent water-quality monitoring of both the intake-system water, to distinguish S-Area's contribution from the river's loading, and the finished (distribution) water. Any detected problems or elevated chemical levels (above an established background level) will prompt immediate corrective action.

A highly-impervious surficial cap will be placed on the contaminated portions of the property.

CONCLUSIONS

Three years of negotiations have produced an agreement setting forth a workable solution for the problems created by S-Area. This negotiation process represents a practical resolution of this case. Even though the years of negotiations might seem too lengthy, there was no guarantee that a more satisfying solution could have been obtained by taking the case of trial or by invoking the statutes of CERCLA. The experience gained at S-Area and the proposed agreement produced in the case have already been used by the USEPA and the State in other negotiations.

The USEPA invested significant extramural funds, although the burden of supplying the data lay with Hooker. And, even though the USEPA's and the State's oversight will be costly, the remedial program will cost Hooker a minimum of approximately $36,000,000. An environmental hazard of national significance on the Niagara Frontier will be remedied. The settlement agreement represents, therefore, a milestone in joint efforts of the USEPA and the State.

Thorough investigation and rigorous evaluation of all elements of concern allowed the proposal of an overall program (strategy) to protect the public health and welfare and the environment. The program will continue as long as an endangerment exists. The remedies set forth in the settlement agreement are dynamic, useful and effective. With regard to the hazardous wastes, this program is designed to achieve total containment and maximum feasible collection of chemicals.

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CONSTRUCTIVE CRITICISM ON THE IMPLEMENTATION OF THE SUPERFUND PROGRAM—A STATE PERSPECTIVE

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INTRODUCTION

The purpose of this paper is to discuss selected problems states are having with implementation of the Federal Superfund program. The discussion will include descriptions of the problems and proposed solutions from a state's perspective. The issues to be addressed in this paper were selected from three different data sources: a survey of all states conducted by the author and returned in August of 1984, a survey conducted by the Association of State and Territorial Solid Waste Management Officials between November, 1983 and April, 1984 and a survey conducted by the Northeast Midwest Institute of 18 States in the Spring of 1984. These three surveys covered a wide variety of problems. Those problems that were prominent in all three surveys were selected for discussion. The discussion of the problems and solutions represents a synthesis of the combined responses from various states.

Before addressing specific problems, it is appropriate to recognize that this program is relatively new compared to most federal programs, and as such, would expect a certain number of growing pains. Improvements have been made in the program over the past 14 months, and states are optimistic that the program will continue to improve. Clearly not all of the problems are caused by USEPA. The states can take credit for some of the problems, such as cumbersome procurement procedures, a lack of coordination with the Attorney General's Offices, unwillingness to commit the necessary state resources to be a full partner in the program and a tendency to sit back and let the Feds run the program.

Everyone understands that all the hazardous waste dumps were not created yesterday nor will they all be cleaned up tomorrow. Hopefully, by raising these issues, the state's administrative agencies, attorneys general, USEPA contractors, Justice Department, the Army Corps of Engineers and responsible parties can work together to improve and streamline the Superfund program to accomplish the mutual goal of cleaning up hazardous waste sites more thoroughly, rapidly and cheaply than otherwise could be accomplished.

The ten issues that will be discussed in this presentation are:
- Lack of delegation of authority to regional offices
- Inability to obtain approval in a timely manner for quality control/quality assurance plans
- Lack of state program support
- Constantly changing guidance
- USEPA contractors and Army Corps of Engineers performance
- Contract laboratory program constipation
- Operation and maintenance costs borne solely by the states
- The unanswered question of how clean is clean enough
- Inadequacy of the hazardous ranking system
- Too much bureaucracy

DELEGATION OF AUTHORITY

The lack of delegation of authority from headquarters to the regions has created a giant bottleneck and is substantially delaying cleanup efforts. The following are some typical state comments on this issue. Headquarters is trying to administer CERCLA in the same way throughout the country. Decisions are made at too high a level in the Agency. Anything you try that is innovative is slowed down or blocked from approval at headquarters. If it is new, it is bad. Headquarters staff lacks state or regional level field experience so they play it bureaucratically safe by refusing to agree to let states try new approaches to problem solving.

Headquarters must change its attitude and start trusting their regions and the states more. Are so many bureaucrats needed to review every decision? At this rate all can retire in the job 20 years from now and never clean up a single site. Most administrators agree that in the formative years of a new program a close rein must be kept in order to ensure a desired amount of consistency. However, there comes a time to decentralize and delegate authority to the regional offices. That time is now.

The solution to the problem is to establish a clear time table for delegation of authority to the regions. Areas that should be delegated are: grant making authority once a central budget has been established; immediate and planned removal decision-making; selection of remedial response alternatives; decisions on cleanup level as long as the levels are consistent with applicable guidance.

QUALITY CONTROL

The next problem is the inability to get quality assurance/quality control plans approved. This has been a major holdup in proceeding with remedial investigation feasibility studies. In numerous instances, states have had to proceed with RI/FS without QA/QC approvals. In some regions of the country, there are more projects underway without approved QA/QC plans than those with approved plans. This is a problem irrespective of who prepares the plan, since states have had as much difficulty getting plans approved as USEPA contractors and state contractors.

There are many projects on hold throughout the country because of the delay in approving QA/QC plans. In some instances, federal contractors have been told to proceed by the regional offices without a plan approved by the regional offices. The problem has been a lack of sound specific guidance on what is expected. Trying to get a plan approved is like a guessing game. The state guesses what the region wants, and then the region plays Monday morning quarterback and writes 25 page critique letters demonstrating how much they think they know about the subject.

If this is going to be a game of nit-picking, then the States need to know which nits the USEPA is going to pick. It is inefficient to

go through two and three rewrites of these plans, spanning from six to 12 months, with turnaround review times taking from one to two months. In some cases, it appears as though the USEPA is afraid to make a decision to approve a plan. To make matters worse in some regions the group which approves or more appropriately disapproves the QA/QC plan does not work for the same organizational unit as the Superfund staff. This sets up a situation where the QA/QC people do not share the goals of proceeding rapidly with cleanups. They only worry about 100% accuracy and 100% cost recovery.

Everyone wants quality data which are adequately documented for cost recovery purposes, but the tail should not wag the dog. The solution to the problem is to provide clear, specific guidance followed by workshops to disseminate the information to the states. Then the USEPA should follow the guidance in reviewing the plans. They should place the QA/QC plan under the same administrative head as the Superfund program in all regional offices.

STATE PROGRAM SUPPORT

The third problem is the lack of state program support of any kind in the Superfund program. Arguments have been made and legal interpretations given as to why states cannot receive program grants. Most of the arguments center on the problems of cost recovery or lack of authority for such grants. The states all hope the law will be amended to specifically provide for such a grant. But if it is not, the USEPA should rethink some of the past interpretations and policies to be more flexible on this issue.

Following are some problems and ridiculous situations being created by the unwillingness to provide program support to states. States cannot hire and train staff until a cooperative agreement is signed, but as soon as it is signed the state is expected to "hit the ground running."

The Justice Department has asked states to forgive future oversight costs at cleanup sites during consent decree negotiations because the USEPA is willing to forgive this cost and it will aid in settlement negotiations. The USEPA then tells the state it will cover this cost in a continuing cooperative agreement on the project. Then, when the consent decree is signed by the state, the USEPA refuses to renew the cooperative agreement for any purpose, which leaves the state "holding the bag."

To add insult to injury, the USEPA then uses the fund to pay its staff and the Army Corps of Engineers to do the same job at a higher cost than it was previously paying the state. When the Army Corps of Engineers fails to provide adequate oversight at the project, the regional office calls the state to be updated on project status.

Possible Solution

The solution to this problem is for the USEPA to think about ways of providing sustained program support instead of finding reasons not to. The multiside agreement concept is a good start, but the prohibition on funding any state cost after a consent decree is signed must be changed. This is a ridiculous scenario when it plays itself out and causes increasing overall costs to the fund. If this latter ruling on state oversight of negotiated cleanups is not changed, there could be a trend for states to refuse to sign off on consent decrees.

CONSTANTLY CHANGING GUIDANCE

The fourth point concerns the problem of constantly changing guidance that slows down the cleanup process by causing work to be redone once completed. As we say about Illinois weather, "If you don't like the weather, wait a day; it will change." This observation could also apply to Superfund guidance. The continual shift of policies and emphasis in guidance is counterproductive; it keeps the entire cleanup effort shooting at a moving target. The solution to this problem is to not issue guidance until it is well thought out. Once it is issued, make it broad enough to be flexible so there is no need to change it for specific cases or situations.

CONTRACTOR SUPERVISION

The fifth problem revolves around the lack of supervision of the USEPA contractors. USEPA regional offices need to stay in closer contact with the hired contractors including the zone contractors, remfit contractors and the Army Corps of Engineers. Contractors need closer supervision or regular contacts with USEPA staff.

The current system is set up to let contracts and not have much more contact until the RI/FS is completed. Penalties need to be included in contracts for late delivery of work products. The cost of some consultants is excessive, and study costs may exceed the cleanup cost on some projects. The Army Corps of Engineers is not necessarily the best group to design projects and supervise cleanups on all federally-led projects.

The USEPA should have the authority to retain the Corps if it is appropriate and not be forced to use them on every job. The Corps is not staffed in every office to handle cleanup supervision in an on-scene coordinator role. The solution to this problem is to provide more staff at the regional office level so that more time is available to work in close conjunction with the contractors throughout the project life span. In addition, the USEPA should not be required to utilize the Army Corps of Engineers unless it deems it appropriate to do so.

OVERWHELMING THE LABORATORIES

The sixth problem is the constipation of the contract laboratory program. This program has become bogged down and swamped so that it is of little practical use to most states and many regions. Long delays are encountered in obtaining results, thus delaying the overall rate of cleanup efforts. The solution to the problem is to put more resources into the program which will cause more organic analytical capability to become available in the United States. If QA/QC plans could be approved more rapidly for state laboratories, more states would develop their own laboratory capability.

FUTURE O&M COSTS

The seventh problem is that future operation and maintenance costs are going to exceed the ability of many states to keep cleanup systems operational and secure. There is confusion over where construction of the design solution stops and operation and maintenance begins. The USEPA would not be favoring the lowest, short-term cost, "quick fixes" which favor land disposal if they had to operate and maintain the constructed systems forever like the states will have to do.

The USEPA would become more cognizant of the O & M costs if required to fund them over an extended period of time. If the USEPA were funding the O & M costs over the design life of the system, more expensive short-term solutions that cost less over the long-term would be selected. This change in philosophy would encourage more capacity to be built into incineration, pyrolysis, fixation and recycling systems.

In addition, treating groundwater would take on a more favored status rather than placing large volumes of contaminated soil in vaults or providing slurry wall and clay caps for contaminated soil and water. The solution to this problem is for O & M costs to be shared at the 90% federal and 10% state rate over the design life of the project.

HOW CLEAN IS CLEAN?

The eighth problem involves the uncertainty as to how clean sites must be to be deleted from the national priority list. The lack of guidance on this issue keeps the states guessing what cleanup standard to strive for. If the USEPA has some ideas on the issue, they should issue guidelines on the subject. Unnecessary delays are caused by having headquarters second-guess the regions and the states on cleanup levels.

The solution is for the USEPA to publish guidelines on the most frequently found contaminants at the NPL sites. For those com-

pounds where guidance is lacking, the USEPA should state the cleanup level they prefer at the beginning. If they do not, they should not require alteration of the cleanup level before the plan is approved.

HAZARD RANKING SYSTEM

The ranking system is the ninth important problem. The HRS system does not adequately consider major environmental degradation to ecologically sensitive areas, aquifers not used for water supplies or threats to fish and wildlife. The HRS scoring system needs to be more flexible to allow major environmental degradation in nonpopulated areas to be dealt with by placing these sites on the national priority list. An alternative would be to allow each state to place one project per year on the national priorities list even though the project scored below the cut-off score.

BUREAUCRACY

The last problem to be treated is bureaucracy. The administration of the Superfund program has become so cumbersome and so complex that cleanup progress is being stifled. Symptoms of this problem are slow or no decision-making, lack of coordination between various branches and regional offices and between regional offices and headquarters, an abundance of constantly changing superfluous guidance, poor coordination between the USEPA and the Justice Department and between the USEPA and the Army Corps of Engineers, slow turnaround times on reviewing documents and reports and too many people reviewing the same reports.

The solution to this problem is to streamline processes with less paperwork and more real work in the field. The closer to the problem the decisions are made, the faster and better the decisions will be.

CONCLUSIONS

In spite of all the problems this new and exciting Superfund program is having, it still has the potential to be the most beneficial environmental program this nation has ever seen. The author is confident that if all try hard to communicate and cooperate, the problems discussed in this presentation can be resolved in a timely manner and a great program will be really Superfun(d).

IMPLEMENTATION OF RCRA SECTION 3012 AT 160 HAZARDOUS WASTE SITES IN WASHINGTON STATE

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INTRODUCTION

Section 3012 of RCRA provides that all state environmental programs develop inventories and preliminary assessments of past or present hazardous waste storage or disposal sites. The USEPA has designed the RCRA 3012 program so that the products of the program (i.e., an information search and a priority designation) integrate with the implementation strategies under the CERCLA program. USEPA guidance toward implementing RCRA 3012 was published in early 1983. Concurrently, the USEPA distributed approximately $10,000,000 to the states to fund preliminary assessments at uncontrolled or potentially hazardous waste sites. Based in part on an inventory containing approximately 470 potential hazardous waste sites, the Washington State Department of Ecology (WDOE) was given USEPA grant assistance to perform RCRA 3012 preliminary assessments at no fewer than 160 sites.

As the lead environmental protection agency in the state, the WDOE has established and is developing a staff expertise for the sole purpose of implementing RCRA, Superfund and related hazardous waste programs at the state level. During the last two years, the WDOE has surveyed hundreds of known or suspected waste disposal sites, public and private generators of hazardous wastes and those groups which collect and store, transport and treat or dispose of hazardous wastes. Through careful analysis of the available information, the WDOE identified more than 470 sites as potentially hazardous waste sites.

Recent legislation passed by the state of Washington provides both the statutory authority and an appropriation for the WDOE to initiate site investigations and remedial responses to improper hazardous waste management practices on those remaining Emergency and Remedial Response Information System (ERRIS) or other identified sites not presently on the National Priorities List (NPL) register. The WDOE is pursuing cooperative agreements with the USEPA to continue site investigations at a number of NPL sites.

In early 1984, the WDOE contracted with JRB Associates to provide technical support in the records search and off-site cursory examination of 160 potential hazardous waste sites contained in the USEPA's ERRIS files and to assist the WDOE in the assessment of these sites and determination of need for further site investigation and remediation. JRB Associates was directed to perform RCRA 3012 Preliminary Assessments (PAs) utilizing the guidance documents and control forms contained in USEPA Form 2070-12.

In this paper, the authors present the results of implementing RCRA 3012 in the state of Washington. Key issues reviewed include the methodologies utilized in the search for records within multiple-tier agencies and across a wide geographic distribution;

the difficulties encountered during the records search and PA composition and how they were rectified; the success employing quality control protocols to insure timely and technically consistent site assessments; and methodologies employed in determining environmental risk for ultimate use by the WDOE and EPA in re-ranking and updating the NPL of hazardous waste sites.

OBJECTIVES AND RATIONALE

Under Section 3012 of RCRA, each state is required to establish a program that identifies and inventories the locations of any site within that state that stored or disposed of hazardous wastes (Fig. 1). Following the site's discovery process, the next step is to complete a preliminary site assessment. This activity involves the collection of accessible information regarding a potential or known hazardous waste site, using this information with a cursory environmental characterization to determine the probability of human health or environmental consequences and making an assessment of the degree of risk and need for further actions.

The preliminary assessment should describe information regarding the site's current location and ownership; the hazardous substance's physical state, quantity and waste characteristics; the potential pollutant mobilization routes and probable targets; and any information concerning potential or real hazardous conditions or incidents attributable to that site. It should also describe land use and facility management practices and the potential parties responsible for the site and its conditions.

All of this information is presented in the Potential Hazardous Waste Site Preliminary Assessment form (USEPA Form 2070-12 [7-81]). Upon review and a quality assurance control check, much of the data are transferred from the PA and entered into the USEPA's ERRIS files. The ERRIS file is the centralized data base which tracks the history of a hazardous waste site until its final disposition is achieved and the site is delisted from the ERRIS register.

The PA is primarily intended to be an "efficient in-office review" rather than a comprehensive and complete program records search, intensive site survey or field reconnaissance effort. The assessment confirms the site data if they exist in the ERRIS files, expands the existing data base with physical and cultural data and relationships of the same with the site and, finally, provides a determination if the site potentially poses a problem. If there is a problem, the type and timing of followup work that should be undertaken is delineated.

The information gathered during this process is crucial to the ultimate determination of a site's fate. The PA's conclusions will justify the need for further data gathering and documentation effort as well as a site inspection which precedes hazard ranking

Site Discovery

Preliminary
Assessment

Site
Inspection

National Priority List
Nomination

Remedial Plans
and Actions

1. Name, Location, Ownership

2. Responsible Parties

3. Brief Site Description

4. Hazardous Substance Information

5. Environmental Descriptions

6. Demographics

7. Land Use Information

8. Pollution Mobilization Routes and Targets

9. Priority Designation

10. Conclusions and Recommendations

EPA Form 2070-12

Figure 1
Integration of RCRA §3012 Program with Implementation
Strategies of the CERCLA Program

and NPL nomination. In some cases, the PA may go beyond an initial screening and actually provide enough documented information to permit a Hazard Ranking System (HRS) score which further evaluates the magnitude or severity of that site's hazardous wastes problem. Based on the assigned value, a site may then be nominated for NPL inclusion.

In consideration of the above, it is clearly evident that despite the cursory nature of the PA's data gathering efforts, this phase within the CERCLA remedial response program represents a decisive and significant step in the recognition, evaluation and ultimate mitigation or correction of hazardous waste disposal problems.

METHODOLOGIES

JRB Associates approached the performance of all project tasks within an organized and sequential chain of activities (Fig. 2). The RCRA 3012 preliminary assessments were performed in four phases:
•Phase 1-Project definition
•Phase 2-Records and information search
•Phase 3-Correction of data deficiencies and assemblage of the preliminary assessment
•Phase 4-Review and PA finalization

Each of these phases provided for a timely flow and thorough performance of the overall assignment.

Project Definition

In Phase 1, Project Definition (Fig. 2a), coordination with the WDOE headquarters and its four regional offices was initiated in order to establish proper protocols and make key staff contacts. This action also familiarized JRB staff with state files, programs, records, indexes and resource locations. During this initial coordination, JRB was able to determine the format and material types necessary for data base deliverables that would fulfill the needs and requirements for WDOE computer/word processing systems.

Finally, contacts were arranged with appropriate federal and local agencies such as USEPA-Region X and county health departments to establish similar coordination and records access.

Upon completion of this groundwork, JRB and WDOE staff finalized a performance schedule that would satisfy the state's requirements. Flexibility was maintained within this schedule by batching PAs into groups of approximately 30 to 35 sites with interim deadlines in order to achieve concurrent draft PA review and quality control with the state personnel. This also allowed the WDOE to make any site substitutions on the latter batches should pertinent information surface regarding any new site(s) that would require immediate attention. Finally, the selection of JRB project team leaders and specific site assignments set the stage for site information collection.

Records and Information Search

During Phase 2 (Fig. 2b), the Records and Information Search, all levels of government (federal, state and local) were targeted for each site's investigation. Private agencies contacted were usually limited to research or consulting firms that had been contracted by regulatory or public agencies to perform pertinent hazardous waste investigations and to private haulers of solid or liquid wastes known to or suspected of hauling wastes from or to a particular site. The information searches undertaken included reviewing existing agency files; communicating with knowledgeable staff; researching ongoing studies; reviewing archives or historical records; collecting technical references; visiting local and regional libraries; and compiling media releases. Specific information sources for completing the 2070-12 form included:

Waste Types and Quantities—Because of the specificity of the information, agency records, ongoing studies or familiar staff appeared to be the best sources. Examples of technical references used included:
•NFPA's *Fire Protection Guide*
•Sax's *Dangerous Properties of Industrial Wastes*
•NTIS' *Water Related Environmental Fate of 129 Priority Pollutants*
•Brown's *Ecology of Pesticides*
•NOAA's *Puget Sound Marine Ecosystem Analyses*

Geology and Hydrology—Sources included:
•U.S. Geological Survey
•Geohydrologic investigations and reports
•Well logs
•Water supply bulletins and monographs
•Washington stream catalogs
•USGS stream flow data
•Physiographic and topographic maps

Natural Resources—Sources included:
•U.S. Fish and Wildlife Service
•Washington Department of Natural Resources
•Washington Department of Game
•Washington Department of Fisheries
•Washington Natural Heritage Program
•National Wetlands Inventory
•National Weather Service
•Regional air pollution control authorities
•Local regulatory and conservation organizations

Social and Human Resources—Sources included:
•Washington Department of Social and Health Services
•Local county health departments
•Local water and sewer districts
•Public utilities and irrigation districts
•Federal, state and local census data
•Puget Sound Council of Governments
•Business license maps and records
•Flood Insurance Rate Maps (FIRM)
•Tax Assessments
•State archives

Figure 2a
Performance of RCRA Section 3012 Preliminary Assessments for WDOE

Phase II   RECORDS INFORMATION SEARCH

Figure 2b
Performance of RCRA Section 3012 Preliminary Assessments for WDOE

Phase III - DATA DEFICIENCY CORRECTION AND PREPARATION OF FORM 2070-12

Figure 2c
Performance of RCRA Section 3012 Preliminary Assessments for WDOE

maps and site sketch, was added to the main site file record following all "windshield surveys."

At the conclusion of the records search and site survey, the 2070-12 form was prepared and began a rigorous in-house quality control review. To ensure compatibility and accuracy among the site assessments, the task of reviewing and adjusting the PA was assigned to the team leaders and project manager, who evaluated each assessment for overall quality and completeness. Guidelines on PA priority rankings were provided by the WDOE and are as follows:

- *High*—Imminent health or major environmental threat highly suspected
- *Medium*—A site is highly suspected to present a potential problem; evidence from sampling, direct observation by regulatory agency or history of problems at site
- *Low*—Unresolved question but not highly suspected; alleged problem (tip from employee or member of the public) or unknown how facility disposed of suspected hazardous waste
- *None*—No evidence to suspect a problem

During this time, the form was also entered onto a data base management system, utilizing JRB's inhouse microcomputer, an IBM PC. This data base management system, recording all preliminary assessments, is compatible with WDOE's data base management system. This computerized information management system was prepared specifically to accept the RCRA 3012 data base.

Review and PA Finalization

Upon a final satisfactory review by the team leaders and a determination by the JRB project manager that the PA satisfied internal quality control standards, the PA was ready for submission to the WDOE.

When the batch of site assessments had been compiled, they were organized and identified by priority ranking and level of risk. At this point, they were transmitted to the WDOE for Phase 4 (Fig. 2d). A report summarizing all of the assessments accompanied this deliverable which briefly highlighted the categories of

Phase IV - REVIEW AND PA FINALIZATION
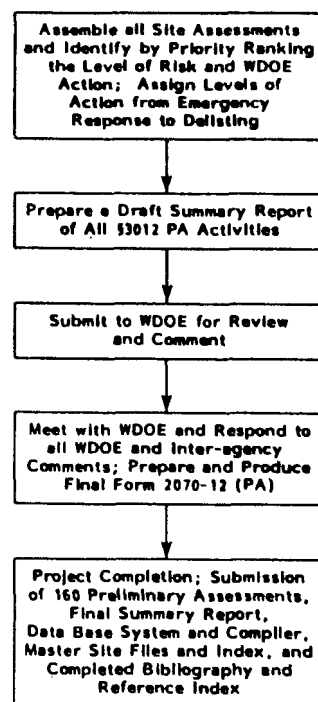
Figure 2d
Performance of RCRA Section 3012 Preliminary Assessments for WDOE

Files were established for each site as information was generated, and photocopies of records and documentation of all telephone and in-person contacts were maintained to insure record verification and to facilitate the inclusion of these data on the PA. A completed bibliography and contact summaries with all appropriate information sources were maintained and updated for use as a final deliverable.

Correction of Data Deficiencies

Any data gaps or deficiencies were rectified during Phase 3 (Fig. 2c) if that information was reasonably accessible or if the team leader determined that the budget and time constraints were not strained by a more rigorous investigation (20 to 40 hr has been estimated as the appropriate range of time required to fully complete a PA). Off-site or "windshield surveys" were also implemented during this phase. They were extremely useful for determining the current status of a site as well as collecting additional information regarding its environment and its potential risks. A site survey memorandum, including travel directions, location

waste sites, clarified the priority ranking and identified problem areas or persistent data gaps. This report also summarized JRB recommendations to remedy informational needs and presented technical guidance for possible remedial or mitigative actions. The WDOE, therefore, had sufficient information to pursue its own review and edit each potential hazardous waste site. Concurrent with the state's review, JRB commenced work on the next batch of site records search and assessments.

A meeting with WDOE's project manager and staff to review all WDOE edits and questions was the final step in Phase 4. The PA then underwent a final revision and was resubmitted to WDOE in a final form with backup copies. At the conclusion of all 160 preliminary assessments, a final summary report, the data base system with a compiler, the master site files and index and a completed contract summary and bibliography were also submitted.

RESULTS AND DISCUSSION

After completing 160 preliminary assessments for the WDOE, the staff at both JRB and WDOE determined that the amount of time predicted to complete average site assessments was approximately 24 working hours, well within the original time estimate. JRB also believed it achieved great success in employing quality control protocols that resulted in timely deliverables and quality products. Diligence in maintaining strict documentation protocol was well rewarded during state and inter-agency reviews. JRB cannot overemphasize the importance of maintaining precise records of information sources.

Some aspects of the PA process were fraught with difficulties, and the following discussion elaborates the source of problems as well as the methods JRB utilized to overcome them.

The culmination of the records search, file documentation, site surveys and the interpretation of all the above optimally leads to a completed PA. The completed Form 2070-12 should contain enough information pertaining to a potential site's risks as well as its environment to permit the reviewer to assign a rank of high to none indicating the degree of need for further site investigation and monitoring activities. Based on this ranking, the concerned agency can then begin remedial action. The first difficulty encountered in this process was interpreting each ranking designation. Fortunately for the JRB staff, WDOE provided guidelines for designating a ranking. However, it would also have been useful if specific regional examples had been provided by the USEPA that could have facilitated the initial scoring process. The necessity to produce a standard for assessing potential hazardous waste sites cannot be disputed, but the variability within a region and the degree of concern by local regulatory agencies can often complicate the overall objective.

Based on the completion of over 160 PAs for the WDOE, approximately 30% of the sites had sufficient information available in various existing files or records systems to assemble a completed Form 2070-12. An additional 20% required information to complete assessments; the information was easily obtained by verbally contacting WDOE inspectors and local health or public works officials. Cooperation from these various agencies was not only gratifying, but also very illuminating because local authorities often had ample familiarity with a potential site due to their proximity to it. For the remaining 50% of the sites initially nominated to receive the assessment, either very limited information was available regarding the final fate of hazardous wastes or the sites were often no longer in operation with few or no records regarding the types of wastes generated or handled. For example, small metal plating and fabricating industries were sites for which there was often little file information regarding the final destination of their dragout sludges. In all of these cases, a 2070-12 form was completed for each site with JRB's recommendations for contacting the owner or operator and/or a detailed site investigation.

A common difficulty encountered related to sites that were selected for review based only on rumors or complaints and without any additional background information that would allow a complete assessment. In these cases, the records search revealed nothing more than an initial complaint record with perhaps a subsequent site inspection that could not resolve or identify a specific problem. This situation, of sourse, is not unusual and it proved to be challenging to JRB staff. Essentially, the reviewer sharpens his or her investigative skills to provide, at a minimum, a description of the site's environment in order to evaluate targets and pathways for potentially hazardous substances.

A recurrent dilemma was assessing the potential consequences of abandoned landfills. In most instances, these sites were public landfills that were not regulated for the types of wastes received. Others were industrial or otherwise private on-site dumping areas that again may have been inactive and even covered over but would have logically received process waste materials that may or may not have had hazardous components. Oftentimes records were reviewed which documented that landfill leachates were sampled for conventional pollutants (e.g., TOC, pH, COD, BOD, nitrogen, chlorides and specific conductance) and perhaps some of the heavy metals, but not other priority pollutants or hazardous wastes that conceivably could be present. In these cases, it became important to emphasize the hydrological and geological characteristics in order to evaluate risk potential. Where no records existed concerning the types of wastes present, JRB searched local historical resources as well as the state archives in order to provide a description of that site's environment wherein potential waste sources may be located. Old tax assessments and property locator maps were the best sources of this information.

Some sites did not have hazardous waste problems and thus were inappropriate for RCRA or CERCLA response. These frequently were the more classical water quality problems from biological wastes and included farming and rendering activities. While these problems are to be excluded from further RCRA action, it does not necessarily mean that there are no human health or environmental risks. Based on this analysis, JRB completed the Form 2070-12 with as much information as could be derived and documented the presence (or absence) of a problem and the degree of environmental or population risks. This step provided a useful service to the contracting agency that is responsible for a wider range of environmental problems than only hazardous materials or wastes.

JRB encountered several areas of difficulty when completing the USEPA Form 2070-12 that required interaction with the WDOE and USEPA-Region X in order to overcome. A summary of the major difficulties encountered are presented below, and a copy of USEPA Form 2070-12 is presented in Figure 3 with those sections highlighted.

Responsibilities (Part 1, Part III)

The 20-70-12 form does not provide adequate space for distinguishing between past and present owners and operators. Many sites have changed ownership and land usage several times. A provision within the form to enumerate past responsible parties would not only be useful in understanding the hazardous waste site's history, but it could also reduce the amount of future time spent conducting responsible party searches.

Waste States, Quantities and Characteristics (Page 2, Part II)

Quantities of wastes are designated in three categories: tons, cubic yards or number of drums. If the site involves a pool of contaminated materials, it would appear that a liquid measurement such as gallons or liters would provide a clearer picture of that site. This would provide a future site investigation team with a better idea of what to expect before arriving at a facility.

Hazardous Substances (Page 2, Part IV)

The chemical concentrations of hazardous wastes can be reported in several ways. The form should distinguish between the results of environmental release analyses from the analyses of the waste materials exclusively. JRB assigned sub-headings within this section to allow for these differences. Chemical Abstracts Services (CAS) numbers should not be included if the possibility exists

Figure 3
EPA Form 2070-12, Page 1

for chemical reactions among hazardous materials or between wastes and natural elements. The assessor may not know what the altered chemical states are without precise analytical data. Confirmed environmental contamination at some sites was difficult to establish from background levels if the contaminants were similar to elements found naturally. An example of this situation was landfill leachate with low levels of heavy metals. Inadequate data on these background levels preclude adequate assessment of risk and judgment that contaminants were above the natural concentrations.

Hazardous Conditions and Incidents (Page 3, Part II)

Site specific geologic and hydrologic data are an important factor in determining risk assessments. Geology in the mountainous regions of Washington is quite diverse. Attempting to define characteristics of the aquifer of concern and its appropriate stratigraphic sequence may not always be precise, particularly in remote or unpopulated regions if there are no well logs or specific geological information available. Furthermore, defining the aquifer of concern in northwestern Washington in areas not serviced by municipal supplies may not be a simple task. Water bearing zones

Figure 3
EPA Form 2070-12, Page 2

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are numerous and distributed throughout the stratigraphic column. Depending on personal preference and expense, private wells can, and do, tap a multiple of water-bearing strata. Compensation for this problem primarily depended upon the technical knowledge of JRB staff geologists as well as local water purveyors.

Determination of the population potentially affected for potential surface, groundwater, fire or air contamination is based on the HRS guidelines of a one through four mile radius. Using these specified distances required apportioning census tracts or blocks to conform to that area. This apportionment may not always conform to true population densities and clusters.

Continuation of Hazardous Conditions and Incidents (Page 4)

USEPA guidelines indicate that contamination of food chain applies to human consumption of food/forage crops that may be grown on contaminated grounds or are irrigated by contaminated surface and/or groundwater. This section has also been interpreted to mean environmental and biological food chain contamination, a much more complex issue. Predicting or determining biological food chain risks would require a consideration of trophic relationships as well as an understanding of the physiology and compensatory characteristics of many organisms. Thus, it may be wiser to avoid speculation of biological food chain contamination on a

POTENTIAL HAZARDOUS WASTE SITE
PRELIMINARY ASSESSMENT
PART 3 - DESCRIPTION OF HAZARDOUS CONDITIONS AND INCIDENTS

I IDENTIFICATION

II. HAZARDOUS CONDITIONS AND INCIDENTS

| 01 A GROUNDWATER CONTAMINATION | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 B SURFACE WATER CONTAMINATION | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 C CONTAMINATION OF AIR | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 D FIRE EXPLOSIVE CONDITIONS | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 E DIRECT CONTACT | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 F CONTAMINATION OF SOIL | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 AREA POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 G DRINKING WATER CONTAMINATION | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 H WORKER EXPOSURE INJURY | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 WORKERS POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

| 01 I POPULATION EXPOSURE INJURY | 02 OBSERVED DATE | POTENTIAL ALLEGED |
| 03 POPULATION POTENTIALLY AFFECTED | 04 NARRATIVE DESCRIPTION | |

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Figure 3
EPA Form 2070-12, Page 3

site-specific basis and report the potential for food chain transfer and known bioconcentration factors of relevant contaminants that are found in the literature.

Contamination of sewers presented another problem to the JRB staff because of the large numbers of districts in some Washington counties. It was often a tedious task locating potentially affected sewer systems and determining the potential for migration risks.

CONCLUSIONS

Based on the completion of 160 preliminary assessments in Washington State, JRB Associates can make the following conclusions:

- The PA process, which encompasses the records search to the final assemblage of the 2070-12 form, can be accomplished in an average of 24 hr.

- Documentation of all information sources is crucial to supporting the final PA ranking and supporting any future actions.

- The easiest data to find in most cases included the description of demography and environmental characteristics such as hydrology, geology, floral and faunal characteristics. Environmental characteristics regarding sites located in remote areas, however, were not always site specific or as complete, and in these cases relevant technical judgments were called upon to provide adequate descriptions.

- The most difficult information to find was the hazardous waste site data such as the types and quantities of materials disposed and the physical characteristics of the site. This was difficult because, in many cases, these sites had ceased operation long ago or had altered their practices and, consequently, no records were

Figure 3
EPA Form 2070-12, Page 4

available to reflect these past practices, number of workers or information regarding access to the site. Whenever this situation occurred, it was imperative to provide, at a minimum a description of the site's environment and, particularly, a historical overview of the types of adjacent land use that was prevalent at the time of the alleged or known hazardous wastes handling. A search through archival records of tax assessments and county property maps provided the most valuable source of this information.

The performance of the preliminary assessments provided the WDOE with a completed Form 2070-12 and associated files for 160 potentially hazardous waste sites, and, more importantly, it provided the state with an awareness of these sites' relative degree of hazard to populations at risk and to the environment. Overall, this awareness is the most beneficial result of preparing preliminary assessments because the process is designed to screen and indicate potential problem sites and can assist the state's determination of the next appropriate action including site investigation, HRS scoring, nomination for NPL or even delisting.

ACKNOWLEDGEMENTS

RCRA 3012 AND SUPERFUND ENFORCEMENT AT THE STATE LEVEL

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THE TEXAS PROGRAM

In an effort to define the number of sites where hazardous substances may have been handled, spilled or dumped, the USEPA set up the Emergency and Remedial Response Information System (ERRIS). At present, over 16,000 potential hazardous sites are represented on the national ERRIS list, and the USEPA estimates that perhaps 22,000 sites ultimately will be identified. The Agency's fiscal 1983 appropriations bill provided $10 million from the Superfund to perform activities authorized under Section 3012 of RCRA. The bill provided for one-time grants to assist states in completing the identification and evaluation of potential hazardous waste sites. The grant allocation for Texas was $677,000 based upon 1,109 sites.

The evaluation process for sites on the ERRIS list involves a sequence of investigations. The first step is a preliminary assessment which is the collection and review of readily available information. Second, if the preliminary assessment determines that a potential hazard exists, a Site Inspection is scheduled. The Site Inspection can lead to additional investigation, emergency actions, enforcement action or ranking of the site for inclusion on the National Priorities List (NPL). In Texas, because of the large number of sites, the state and the USEPA have divided the task of investigating ERRIS sites.

The USEPA's Field Investigation Team (FIT) has evaluated approximately 580 sites on the Texas ERRIS list. The State of Texas is responsible for the remaining 527 sites. Prior to this cooperative agreement, the state had completed investigations on 264 sites; under the RCRA 3012 Program, the State will complete inspections of the remaining 265 sites in 1984.

Site Discovery and Preliminary Assessments

The sites presently listed in ERRIS have been identified through a discovery process. They may have been identified under the RCRA 3012 program or by other means including citizen complaints, existing site notification programs such as RCRA and CERCLA, land use records, aerial photo-imagery or federal, state or local governmental records. The ERRIS list includes only those sites which have been reported to the USEPA and is not a comprehensive listing of all potential hazardous waste sites. Sites will continue to be added to the ERRIS list as they are discovered.

Following site discovery, a preliminary assessment is performed to determine if further action at the site is required. In many cases, the preliminary assessment and site identification activities are combined. The preliminary assessment is a quick, low-cost characterization of the site, including determination of the potential presence of hazardous materials, past and present facility waste management practices, pathways allowing off-site transport of waste materials, potentially impacted populations and responsible parties.

This preliminary evaluation involves review of readily accessible data on the site—usually from federal, state or local governmental agencies. Additional information on land use, flood hazard potential, groundwater resources and meteorological characteristics is typically compiled and reviewed for the preliminary assessment. In some cases, off-site reconnaissance is necessary to provide additional information.

The completed preliminary assessment can result in one of three actions. In certain cases, where an imminent threat to the environment is identified, emergency response may be warranted. In other cases, the preliminary assessment may result in a recommendation of no further action. However, in most cases, the site will be scheduled for a site inspection to more completely identify potential hazards and to obtain additional information.

A total of 177 preliminary assessments were performed under the Texas RCRA 3012 program. Of these, none were identified as requiring immediate emergency response.

A total of 82 of these sites were found to have no on-site hazardous waste handling or disposal or were determined to pose no hazards to the environment. Many of these sites were municipal landfills used for domestic waste disposal only or sites which had already been closed under TDWR supervision. Trash and waste haulers with no on-site waste handling, who disposed of wastes in landfills already listed in ERRIS, were also identified in this group. Off-site reconnaissance was conducted at a large majority of these sites and was invaluable in identifying sites where no further action was necessary. The remaining 95 sites were recommended for on-site inspections to further delineate potential hazards.

Site Inspections

The purpose of a site inspection is to characterize potential hazardous waste sites by providing a data base sufficient to screen out sites which will not be a problem, provide additional information for state enforcement activities or complete the hazard ranking system (HRS) on sites that do pose a problem.

Objectives of a site inspection include the confirmation of preliminary assessment data, development of data unavailable during the preliminary assessment and an update on site conditions if there are indications that undocumented changes may have occurred.

It is important to provide analytical evidence that a legitimate hazardous waste control problem exists. The site inspection accomplishes this through sampling both on-site and off-site to obtain evidence that hazardous materials are present on-site and to demonstrate the migration of such materials off-site. These studies are limited efforts and are not intended to take the place of a comprehensive field investigation.

The site inspection is not an intensive, complete environmental assessment. Rather, it is a quickly implemented investigative effort limited to gathering data. Site inspection activities are restricted to: field measurement of ambient conditions, the documentation of observations regarding hazard conditions at the site and at sample collection locations and the collection of grab samples including samples from on-site soils, waste spillage, open waste containers, waste pits and lagoons, off-site soils, surface waters and groundwaters.

Specifically excluded from site inspection activities are geophysical testing, groundwater monitoring well installations and all other activities that require detailed prestudy or specialized techniques. Finally, studies aimed at identifying the extent of contamination,

rather than its existence, are beyond the scope of a site inspection. If such activities are warranted, they are undertaken during site inspection follow-up activities.

Under the RCRA 3012 program, 171 sites have been inspected including 95 identified from the preliminary assessment stage. All of these inspections involved on-site interviews with facility personnel, and many involved collection of soil, sediment and water samples. Of these inspected sites, approximately 45% were determined to pose no hazard to the environment and therefore no further action was recommended under the RCRA 3012 program.

The remaining sites were assessed a low or medium hazard potential, based on the type and quantity of waste materials present, waste containment, pollutant migration pathways and potential receptors. Many of the sites for which a medium hazard potential was assigned were already under enforcement and no further action was recommended under RCRA 3012.

Relatively few sites, which had not already been investigated or which were unknown to federal and state regulatory agencies, were assigned a medium hazard potential. However, two sites were selected for site inspection follow-up activities due to suspected problems.

Site Inspection Follow-Ups

Inspection follow-up activities are required where additional information is necessary to calculate or strengthen a HRS score, better define the quantity of waste materials and the extent of contamination or further identify on-site waste materials. At many of these sites, groundwater monitoring well installation is necessary to provide information on subsurface transport of waste materials.

Two sites were identified under the Texas RCRA 3012 program for which additional information was desirable. The first site involves an abandoned petroleum refinery which was dismantled in the late 1940s. Several large impoundments were used for waste disposal and/or crude storage during the active life of the refinery. These impoundments were filled, but much of the waste material remains. Portions of the property have been sold, and a warehousing complex was constructed over the largest of the former ponds in the late 1970s. During construction, quantities of oily sludge were uncovered, causing illness in several workers at the site and causing odor problems in neighborhoods which had developed nearby. The follow-up inspection involves the collection of surface soil samples to identify possible off-site transport of waste materials in surface drainage pathways. Soil borings and groundwater monitoring wells are required to evaluate the subsurface geology and potential subsurface transport mechanisms as well as the depth and extent of buried wastes.

The second site inspection follow-up involves an inactive landfill formerly used for the disposal of magnesium sludge from a nonferrous metal alloy producer. At the time of disposal, this material was still reactive and, in the past, had caused several fires in the disposal area. Although the inactive landfill is heavily overgrown with scrub brush and a few small stands of trees, extensive piles of the magnesium sludge are still evident. On-site investigative activities will include soil and sediment sampling of drainage pathways and drilling of groundwater monitoring wells to determine the potential for subsurface migration of heavy metals. Samples of the remaining waste material will also be collected to determine its current characteristics, including reactivity.

SUPERFUND ENFORCEMENT

With the identification of hazardous sites under RCRA 3012, there is a need for site restoration strategies. If sufficient documentation exists to indicate which parties are involved, then an enforcement program is appropriate. In Texas, the TDWR has developed such a program.

Prior to the enactment of the Texas Solid Waste Disposal Act in 1969 and the RCRA in 1976, the generation, storage, transportation and disposal of hazardous waste was regulated only indirectly, if at all, through a stretch-to-fit application of state water quality legislation and public health laws pertaining to nuisances. With

time, enforcement activity has increased in scope and complexity and has expanded to include abandoned hazardous waste sites.

The State of Texas gained the initial authority and resources to respond to abandoned hazardous waste sites with the passage of CERCLA in 1980. In 1981, the 67th Texas Legislature passed Senate Bill 758 establishing the Texas Disposal Facility Response Fund. This fund provides the resources for the state to become a managing partner with the federal government in the Superfund program. In February, 1982, the Governor designated the TDWR as the Agency with the necessary authority to develop and manage the Superfund program in Texas.

Based on its existing solid waste enforcement program and its recent experience with the federal Superfund program, Texas has developed an enforcement policy which fosters early and direct commitment, participation and site restoration by parties with documented involvement. Should such a procedure fail, the federal Superfund resources are then tapped.

Enforcement Strategy

The basic strategy in all enforcement cases is the use of enforcement mechanisms of escalating significance. These mechanisms are outlined briefly as follows. Timeframes and other details have been omitted for brevity.

Upon discovery, inspection and development of sufficient documentation, the TDWR District Office will send the affected party a notice. This notice requires the recipient to come to an agreement on a proposed schedule for site restoration. If an adequate response is not received by the District Office, the case is referred to the Solid Waste Enforcement Unit.

The enforcement investigator reviews the case and inspects the site as necessary. Upon coordination with TDWR General Counsel, a conference is then held with the involved party in order to develop a timely schedule for site restoration. The mechanism for attaining this goal is either a compliance agreement signed by both parties or a letter signed by the Executive Director of TDWR. If an agreement cannot be reached or violations of prior agreements are not resolved, the case is referred to the Texas Attorney General or to the TDWR Superfund unit. Restraining Orders to stop dumping and referral to the USEPA for imposition of administrative fines are two additional mechanisms which may be used.

Enforcement Work Scope

TDWR currently has approximately 3,000 Class I Industrial Solid Waste generators and facilities, any one of which could become involved in a Superfund site. As of June 30, 1984, the Solid Waste Enforcement Unit had a total worklist of 321 cases, each with a higher associated probability of becoming involved with Superfund.

A review of this worklist indicates that at least 20 (more likely 30) sites are abandoned with a high likelihood of Superfund involvement. The 20 sites are in addition to the existing 11 NPL sites and 12 proposed NPL sites.

Further examination reveals that enforcement action has produced results or is pending with involved parties in at least 11 of these enforcement cases.

The resolution of these cases has centered upon timely commitment and participation by involved parties with the option of TDWR referral to Superfund. A number of the remaining abandoned site cases do not have a documented responsible party. Apparently, this "Superfund inducement" is an effective enforcement tool. The ultimate decision for the involved party is the expenditure of a site restoration cost now versus the expenditure of a probable higher site restoration cost under Superfund multiplied by the probability of successful USEPA cost recovery action multiplied by a factor of up to three.

Thus, the experience of TDWR suggests that a viable enforcement program can use the "threat" of federal Superfund in a timely and efficient manner to attain site restoration. This effectively broadens the scope of the federal Superfund program at the state enforcement level and indirectly extends the federal program resources.

HAZARDOUS WASTE POLICIES AND MANAGEMENT PRACTICES OF NEW YORK CITY

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INTRODUCTION

There has been a new role emerging for local governments in remedying the problems posed by abandoned hazardous wastes. As testimony to this emergence, one may point to the network of new local regulations imposing penalties against midnight dumpers, the recent activities of local government coalitions like a new organization called the National Association of Local Governments on Hazardous Wastes (NALGOHW) and the efforts that local governments are making to equip themselves and to hire the technical personnel needed to rapidly respond to abandoned waste incidents. While Congress may have intended that federal and state governments take the lead in regulating and remedying hazardous waste problems, the local governments now have reason to get involved since the lack of State and Federal resources has left gaps which must be filled.

URBAN DUMPING

New York City has been quite active in this area since it is faced with some very difficult and unique hazards. While there may be a national perception that hazardous waste dumping occurs primarily in isolated rural areas, there is an urban version which is just as prevalent. This urban problem is extremely difficult to resolve because dumping occurs in small quantities and in numerous locations where the density of buildings is sufficient to provide cover for illicit operations.

What makes urban areas like New York unique is the population and building density. The City of New York is divided into 59 community districts, each district consisting of several neighborhoods. To illustrate the magnitude of the City's population, each of these 59 districts contains an average population of 120,000 persons which means that one district alone is larger than most of the country's 50 major central cities. With an average of 540 persons residing on each acre, hazardous waste problems which might be considered insignificant elsewhere can pose serious health threats; school children, vandals or other persons may come into close contact with the substances. In addition, there are approximately 1,000 businesses, many of them small, which handle hazardous chemicals; as a result, hazardous wastes are present in small quantities in many locations and in places which are not readily identified.

DISCOVERY

Abandoned or uncontrolled hazardous substances are brought to the attention of the City government in either of two ways. First,

citizens may call with eye witness information which may or may not be reliable. Generally, the police are dispatched to verify these calls. In other situations, hazardous substances may be spotted by the city's uniformed forces, including police, fire, sanitation and the medical services emergency units. Generally these uniformed services personnel will discover a hazardous substance problem in the course of their normal dutues. These calls are referred directly to the New York City Department of Environmental Protection (NYC DEP) for response.

In New York City, dumping occurs typically in the streets, inside buildings, in vacant lots and secluded parkland areas and, in the past, at the municipal landfills. Dumping within buildings seems to take place in two circumstances. The first is where a building is used for dumping wastes which have been generated elsewhere. This involves an illicit transporter in an unload-it-and-run situation. Second, and quite prevalent, is the abandonment of wastes after the bankruptcy or closing of a company. In this case, a business generates wastes or uses hazardous materials at its location for a number of years and then goes bankrupt, walking away from both the property and the substances. The City of New York has responded to these and other related problems by developing its own response, investigation, and litigation capabilities.

RESPONSE

Specific response activities include:
- *A field team*, recently expanded to include 17 chemists and other technical staff, responds to calls about abandoned hazardous substances on a 24 hr day, 7 day week schedule. This team responded to more than 225 incidents in 1983 and handled approximately 1000 calls from citizens and businesses seeking advice on hazardous substance problems. In addition, the team has seven laboratory staff which have recently gone on a 16 hr per day schedule.
- *A Motor Carrier Safety Unit* enforces federal, state and local hazardous substance transportation laws. From July 1983 to July 1984 this unit, which as 23 police personnel, issued over 5000 hazardous substances related summonses.
- *A Fire Department Hazardous Materials Unit* is outfitted for hands-on response to chemical emergencies. This unit is equipped with emergency items such as overpack drums and encapsulated suits. Although the city generally engages a licensed contractor to clean up abandoned wastes, the Fire Department Unit provides immediate assistance while arrangements are being made with the cleanup companies.

•A 15 member team of *investigators and attorneys* was recently created to conduct investigations into the identity of responsible parties in abandoned waste incidents.

•A team of four affirmative *litigation attorneys* was also recently created to work on hazardous substance abandonment cases initiated by the city.

In total, the City of New York is spending $3-$4 million annually on hazardous waste program personnel salaries and almost $2 million annually on contracts for analytical work, disposal and related cleanup, exclusive of testing programs underway at several municipal landfills. This annual budget is perhaps double the entire New York State Superfund budget.

CASE HISTORIES

Specific case studies will be described below to further illustrate the different types of waste abandonment problems which are confronted by the City of New York.

Bankruptcies

The city frequently becomes involved in cases where bankrupt businesses walk away from hazardous wastes or materials which were generated while the business was active. Unfortunately, governmental entities are seemingly powerless to stop this type of waste abandonment since the bankruptcy laws, which are structured primarily to protect creditors, allow companies to walk away from their environmental responsibilities.

Quanta Resources

Such was the case with the Quanta Resources site in Long Island City, which is in New York City's borough of Queens. The State had entered into a consent order with this company, resulting from numerous environmental violations, but all attempts to bring the site into compliance had failed. On the evening of May 7, 1982, the NYC DEP received notification from the New York State Department of Environmental Conservation that the trustee for the bankrupt Quanta Resources Corporation had petitioned in federal bankruptcy court to allow an abandonment of the property. The city was further notified that, upon granting of the petition, the trustee would remove guard security and fire prevention and other emergency equipment from the Corporation's oldest and most dilapidated waste oil reprocessing plant.

Following the initial meeting and site characterization, both the State and Federal governments ended their involvement with the site's remedial efforts. The State claimed that State Superfund monies, which are available for inactive hazardous waste sites, could not be made available in this case as the site did not fit the precise definition of an inactive business as contained in the State's environmental law.

On the Federal side, an initial USEPA evaluation using the Hazard Ranking System (HRS) assigned a low priority to the site because potable groundwater supplies were many miles away and neither population density nor poltential air contamination were weighted heavily by the HRS. In addition, there were many unknown factors, such as quantity and precise waste characterization which limited the priority ranking. This, coupled with the USEPA's policy of not taking action at sites where other governmental entities are taking an active interest, sealed the city's fate.

The city, therefore, was forced to secure the site and to perform preliminary analyses of the wastes so that an assessment could be made of the seriousness of the hazard. Abatement of this hazard ultimately involved the removal of over 640,000 gal of waste oils, sludges and water. Much of this material, which was stored in 106 separate tanks, was contaminated with PCBs and other chemicals including corrosives and cyanide salts. The 6 month project involved characterization of the initial waste stream, further site soil and groundwater characterization, and a risk analysis study along with clean-up and disposal. The total cost was $2.3 million, all of which was borne by the city.

The city did, however, press the federal authorities for reimbursement, and had initially submitted a request to USEPA for emergency response assistance. When, after a 6 month delay, the reply arrived, it denied the request, citing a failure to obtain USEPA approval prior to initiation of the cleanup, which is a legal requirement embodied in CERCLA. The city, however, had been unable to wait for the USEPA response as low flash points, four story high tanks which were structurally unsound, 100 °F summer weather, and a strong public outcry had mandated that at least preliminary action take place immediately. The city is still continuing its efforts to identify sources of reimbursement, including an identification of the companies which had contracted for disposal of their wastes using the Quanta Resources Corporation.

Berg Chemical

In a second bankruptcy case, the city has been a little more successful in gaining the promise of future reimbursement; this time from a group of creditors, with the assistance of the Federal bankruptcy court. In the spring of 1984, NYC Fire Department brought to the attention of NYC DEP, the hazardous conditions existing at Berg Chemical Co., Inc., located in the South Bronx. The company was a chemical repackaging facility and a distributor of chemicals, food dyes and detergents; it had filed a petition for Chapter 11 recoganization under the federal bankruptcy law. The company had no valid permits as a hazardous waste generator, no discharge permits, and had been issued many local fire violations. Like Quanta Resources, Berg Chemical was operating pursuant to a consent order negotiated with the State of New York in July 1983.

The city, fearing that the property would be abandoned, conducted an inspection which revealed many potential dangers created by poor housekeeping practices. For example, cyanide compounds and acids were stored in the same area and food dyes and additives were stored next to toxic chemicals, many of which were in damaged or leaking containers. In addition, numerous roof leaks were apparent and there was no functioning fire prevention or fire suppression equipment. Finally, many drums were unmarked and company personnel did not know what was in most of the unlabelled drums.

In an effort to prevent abandonment of the property and over 12,000 containers of various substances, the city applied to the bankruptcy court for relief. In response, the court directed Berg to segregate new products from waste materials; to properly store all new products; to clean up and dispose of all wastes; and to install fire detection and suppression equipment. Unlike Quanta, where the company had already ceased operations, Berg was an active business and was permitted by the court to remain in operation.

The bankruptcy court was then instrumental in getting the creditors to agree to a plan where the city would go in and clean up the site and in return would be given superiority status to become the first creditor to be reimbursed from the proceeds of the ultimate sale of the land.

The cleanup of this site was underway as of August, 1984 and is expected to cost about $280,000.

Other Abandonments

Abandoned buildings are owned by the city as a result of nonpayment of property taxes. This property foreclosure process is mandated by local law and is an automatic process initiated primarily by a finance department computer. The action is triggered after several years of non-payment of real estate taxes. Given the large number of these foreclosures and the automatic nature of the vesting process, physical site inspections do not generally take place until after the city takes title to a property.

Since the City of New York forecloses on hundreds of buildings each year and currently holds an inventory of approximately 1200 commercial and industrial buildings, any type of hazardous waste can be found. Where these wastes are discovered, the city, as the new owner, becomes involved in a cleanup which may cost tens, if not hundreds, of thousands of dollars.

Technical Metals Finishing Corporation

In one such case in 1982, the city was required to prevent the imminent mixing of acid with cyanide salts that were left in an abandoned electroplating facility in Brooklyn which had been operated by the Technical Metals Finishing Corporation. The immediate removal of 12,000 gal of strong acids and base plating solutions in open vats and in damaged containers and the cleanup of cyanide salts on the floor was necessary due to the failure of the company to take proper removal actions prior to abandoning the property. The removal of these substances was deemed necessary by the City to prevent an immediate and significant risk to public health in the surrounding residential community and to the 300 children in the elementary school located to the rear of the electroplating facility. These actions initially cost the city approximately $56,000, but the funds were later recovered by the local district attorney from the president of the corporation.

Following these immediate response actions by the city, the site, which still contained contaminated floor boards and earth, was placed on the state's inactive hazardous waste site list for further investigation and possible inclusion on the state Superfund list.

A year later, when the city took title to the property for non-payment of back real-estate taxes, the site had not yet been evaluated for Superfund status. As the new owner, the city was considered responsible and was compelled to initiate a comprehensive site cleanup and decontamination program which cost about $230,000. While the city may attempt to gain reimbursement from the previous owner or from the state Superfund, it is possible that the city's ownership status will make reimbursement more difficult, if not impossible.

Hospitals

Abandoned hazardous materials are often found after a business closes or relocates. These materials, which are not generally regulated by the same environmental statutes as hazardous wastes, effectively become wastes upon their abandonment. Such was the case with many of the closed hospitals in the City of New York.

In the period between 1974-1980, 46 hospitals were closed in the city. Upon inspection, laboratories and pharmacies stocked with useable chemicals were found in about one quarter of these facilities. This situation apparently occurred because the state, which has authority over hospital facilities and which issues certificates of operation, no longer has authority once a certificate is revoked or expired. Thus, the chemical supplies were no longer useful materials and had become wastes. No government agency, however, had clear authority for following-up in these cases to insure proper cleanup and disposal of the wastes.

This problem was initially brought to the city's attention when the Fire Department reported that biological specimens had been found outside of the former Logan Hospital in Harlem. Upon inspection, it was found that this abandoned hospital still contained large amounts of chemicals, pharmaceuticals, biological specimens and compressed gases. The city immediately placed security on the buildings, and within several days a certified contractor was hired to clean up the site. Over 200 lab-packs along with other potentially hazardous substances were removed from the site in the course of the project.

This incident initiated a year-long investigation into the other closed hospitals. During this time, NYC DEP chemists visited every room in all 46 former hospital facilities. Where past or current owners could be identified, they were required to clean up any chemical or biological wastes which were found. Where no owners could be identified or where the city had taken title to the property, the city assumed the cost of cleanup. Total costs including security, building closure, cleanup and disposal were approximately $670,000.

Because of this experience, new procedures are now employed whenever a hospital is about to cease operation. The state agency which had originally issued the operating certificate calls upon the city to conduct a joint inspection of the property, and the certificate of operation is terminated only after all hazardous substances have been removed. In addition, the NYC DEP investigation encouraged the local Health and Hospitals Corporation to review its storeroom inventories and to hire waste haulers to remove chemicals and pharmaceuticals no longer used. This was done to prevent a build-up of "dead stock."

Other Types of Waste Incidents

There are numerous other examples of hazardous wastes which must be removed by the city including the following:

- Ethers, acids and cyanide salts were discovered as a result of investigation of illegal drug operations; in the period from May to July 1984, over 725 gal of liquid chemicals and 70 lb of solids were collected by the city.
- Municipal landfills have been used for illegal dumping in the past. As a result, millions of dollars are now being spent by the city to characterize air emissions and leachate from these landfills. Operating procedures have been significantly changed so that illegal dumping is prevented.
- With access to the landfills stopped, dumping has increased on the streets and roadways and on parks and other vacant lands. The city has recovered approximately 1500 containers of hazardous substances since 1979 in 300 separate incidents of illegal dumping.

RECOMMENDATIONS

It is necessary for the State and Federal governments to join with local governments like New York City in a partnership to solve these urban hazardous waste problems. Specifically, the efforts of local governments should be recognized and integrated into the national scheme by:

- Introducing into RCRA a "caretaker" status rather than a generator or responsible party status for local governments which acquire hazardous wastes through response to emergency incidents, property foreclosures or inadvertent gifts of contaminated land donated for parks or other municipal uses.
- Providing uniform protocols for all levels of government to use in assessing the degree of contamination and the risks posed by uncontrolled hazardous waste sites, thus avoiding inconsistent techniques and redundant efforts.
- Organizing federal or state technical assistance/technical transfer mechanisms for localities to use when faced with hazardous waste problems which do not quality for federal or state remedial funding. Such assistance might include technical review of cleanup contractor proposals, verification of proposed contractor qualifications, consultation with affected communities and assistance with identification of the responsible parties.
- Reviewing the current site prioritization procedures for urban area needs. Specifically, explosive or flammable situations where the air is a potential pathway to citizens in densely populated areas does not seem to be adequately addressed in the NCP, which is part of CERCLA.
- Amending the federal bankruptcy and environmental laws to insure that the bankrupt company or its successors in interest remain responsible for cleaning up contaminated sites.

It is essential that some of these legislative and regulatory changes be examined. Local governments are on the front lines in the war against uncontrolled hazardous wastes and can offer a great deal toward solving these national problems.

THE NATO/CCMS STUDY OF CONTAMINATED LAND

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INTRODUCTION

The NATO-CCMS (Committee on Challenges of Modern Society) Pilot Study Group on Contaminated Land adopted the following definition of contaminated land:

"Land that contains substances that, when present in sufficient quantities or concentrations are likely to cause harm to man, the environment or on occasions to other targets."

The emphasis on the presence of contaminants means that it embraces the uncontrolled hazardous waste sites of particular concern in the United States, many types of former industrial land (for example, metal mining, chemical production and coal gas production) of particular concern in Western Europe and also land that has become contaminated due to aerial deposition or through the application of sewage sludge "rich" in toxic metals.

As previously described,[1] the Study Group first reviewed the overall problem of contaminated land (identification, assessment and remedial action) in order to decide where it could most usefully direct its efforts. It decided to concentrate on the identification of remedial measures that were effective in the long term. Accordingly, seven projects were established on different types of remedial action and on certain related topics. Thus, The Study was intended to examine in detail a number of important aspects of contaminated land rather than to cover the whole subject. The Study Group has now completed its work and its report[2] will be published shortly. In this paper, the author presents a brief account of the Study and some of its more important conclusions. Other papers in these proceedings describe the outcome of some of the individual projects.

STRUCTURE OF THE STUDY

The Participants

Seven countries took part in the study (Table 1). Eleven CCMS Fellows contributed either directly to the main report or produced related reports of their own[3,4,5] (CCMS fellowships are awarded annually for work related to one of the current CCMS studies).

The Projects

The seven projects are listed in Table 2. The emphasis was on methods of dealing with contamination where it is found. The three main methods identified (on-site treatment, in situ treatment and macroencapsulation) together with control and treatment of the groundwater regime provided the basis for four of the projects. These four, on the practical aspects, were primarily state-of-the-

art reviews within the context set by the project on long-term effectiveness. The project on flammable and toxic gases also dealt with remedial actions but additionally considered the nature of the hazards and their identification and assessment. This latter aspect provided a link to the project on rapid methods of on-site analysis.

Table 1
National Representative Members of the CCMS Pilot Study Group on Contaminated Land

Canada, K.A. Childs, Senior Adviser, Landfill Site Remediation, Environment Canada

Denmark, Ms. K. Warnoe, Environmental Protection Agency

France, P. Godin, Direction de la Prevention des Pollutions, Ministere de L'Environment

Federal Republic of Germany, K. Stief, Umweltbundesamt

Netherlands, J. van Lidth de Jeude, Ministry of Public Housing, Physical Planning and the Environment

United Kingdom, M.J. Beckett, Central Directorate on Environmental Pollution, Department of the Environment

United States of America, D.E. Sanning, Municipal Environment Research Laboratory, United States Environmental Protection Agency

The final report also includes a chapter based on a study by one of the CCMS Fellows on the problems of redeveloping old iron and steelmaking sites in order to illustrate the value of such industry/contamination audits in giving warning of potential problems. The steel industry was chosen because of the large areas of land becoming derelict as the industry contracts in both North America and Western Europe.

Method of Working

The participant countries chose to lead projects in which they already had an interest so that the work done would be of benefit to their national programs. Draft reports were reviewed by correspondence and at meetings of the Study Group. Finally, the individual project reports were brought together by the Study Director as Chapters in the final report[2] which will be published by Plenum Publishing Corporation in 1985. The eleven technical chapters derived from the project reports are supported by an introductory chapter and by a chapter summarizing the conclusions and recommendations of the Study Group. The latter provided the basis for the following sections of this paper.

Table 2
List of Projects Carried Out as Part of the CCMS Pilot Study on Contaminated Land

A   In situ Treatment of Contaminated Sites
Methods of treating the bulk material on a contaminated site without excavation by detoxifying, neutralizing, degrading, immobilizing or otherwise rendering harmless contaminants where they are found.
Project Leader:
D.E. Sanning
USEPA

B   On-site Processing of Contaminated Soil
Methods of decontaminating or otherwise reducing the potential environmental impact of the bulk of contaminated material on a site by: excavation; treatment to detoxify, neutralize, stabilize or fixate; and, usually, redeposition on-site.
Project Leader:
J.W. Assink
TNO, Netherlands

C   Cover and Barrier Systems
Systems designed to prevent the migration of contaminants vertically or laterally or to prevent ingress of surface or groundwater into contaminated sites.
Project Leaders:
   (a) Covering systems:
      Dr. G.D.R. Parry
      Environmental Advisory Unit
      Liverpool University, UK
   (b) In-ground barriers:
      K.A. Childs
      Environment Canada

D   Control and Treatment of Groundwater
Primarily concerned with those operations designed to control or treat the liquid phase on contaminated sites including design of cut-off systems, hydrogeological modelling and groundwater treatment.
Project Leader:
K.A. Childs
Environment Canada

E   Rapid On-site Methods of Chemical Analysis
Methods of chemical analysis allow determinations to be made on "soil", water and air samples on-site to speed and reduce the costs of site investigation.
Project Leader:
M. Gruenfeld
USEPA

F   Long Term Effectiveness of Remedial Measures
Overall problem of the design of long term effective remedial measures. Collection of information on examples of remedial and restoration actions that have demonstrably worked for a number of years and methods for the evaluation of sites for long term effectiveness of remedial measures.
Project Leader:
K. Stief
Umweltbundesamt, FRG

G   Toxic and Flammable Gases
Concerned with: volatile organic emissions from contaminated sites, production, migration and control of gases from land disposal sites including typical landfill gases such as methane and carbon dioxide.
Project Leader:
S. James
USEPA

GENERAL CONCLUSIONS

The Study Group started from the premise that excavation and removal of the contaminated material for deposition elsewhere is not always environmentally acceptable or practicable. In addition, it may not be a "once and for all" solution as the disposal site may itself become a "problem" in the future.'

Remedial actions fall into three main groups:
- Those that remove contaminants or render them harmless
- Those that prevent the release of contaminants
- Those that reduce the rate of release of contaminants

Those falling in the first group are preferred. On-site processing and certain forms of in situ treatment may provide such solutions; the further development of these technologies should be encouraged. Provided these technologies are applied properly, their long-term effectiveness is secured.

The second process is not achievable in practice, although in situ treatments in which the contaminant is chemically converted to an insoluble form under forseeable environmental conditions may provide an essentially permanent solution provided the difficulties of application of in situ techniques can be overcome.

In practice, therefore, all technologies, other than those in which the contamination is destroyed or rendered harmless, offer a solution of only limited or uncertain duration unless other mechanisms, such as microbial attack, reduce the contamination. In general, treatment systems based on isolation (e.g., covering systems and in-ground barriers) are likely to lose effectiveness with time and, like most other civil and structural engineering works, have a finite life. They will need monitoring, maintenance and renewal as long as the contaminants are present and their release would be considered harmful. This is analogous to the monitoring of many civil engineering construction projects (e.g., bridges and dams) and should not be viewed as casting doubt on the effectiveness of the selected solution. Most structures also receive regular maintenance. Funding arrangements should take into account the need for monitoring, maintenance and the need sometimes for a phased approach to remedial action.

The term "effectiveness" can be used to mean different things during the stages of any remedial measure. It can be applied to the performance of a component part of the remedial system (e.g., cut-off wall) or to the system as a whole (e.g., cut-off wall plus groundwater pumping); a distinction can also be made between theoretical effectiveness and installed effectiveness; and long-term effectiveness can be assessed on an arbitrary scale at a point in time or as the ability of the system to continue to perform to an acceptable standard over a prolonged period of time ("performance" is a better term for this latter concept).

Very few of the technologies reviewed have been sufficiently proven in applications specific to the treatment of contaminated land, although they may already be in use for other purposes. It is essential, therefore, to carry out proper long term evaluation studies.

New methods of treatment cannot be proved satisfactorily in the laboratory alone. There is a need for properly designed and evaluated field trials and demonstration projects. Such projects are more likely to be accepted if they are underwritten by responsible authorities.

The evaluation of remedial actions requires the establishment of an adequate set of data before and immediately after treatment and the monitoring of parameters that will:
- Describe the behavior of the remedial system
- Describe conditions within and outside the contaminated area

The Study Group drew a sharp distinction between monitoring and evaluation: monitoring is concerned with whether the remedial system is working properly and is best regarded as a component part of the system; evaluation is closely related to research and may require elaborate instrumentation and inspection.

Retrospective studies of already reclaimed sites may provide useful information on the performance of the treatment strategies adopted but may be difficult owing to a lack of baseline data and an unwillingness by the responsible authorities to have any doubts cast upon the "success" of a completed reclamation scheme.

The long term nature of research into remedial measures designed for containment or stabilization must be recognized. Some projects may need several years for completion, and continued observations may be required over decades; research funding should reflect this time scale.

Records of contaminated sites and of the treatments carried out should be kept unless the contaminants are removed or destroyed. Such records are important since the use of the site may change, the remedial measures deteriorate or knowledge about the effects of the contaminants may change, thereby changing one's perception of the risks.

RECOMMENDATIONS TO CCMS

The Study Group made a number of recommendations' to CCMS; the chief recommendation was that CCMS should encourage member governments to consider the adoption of policies that will:

•Minimize the occurrence of contaminated land problems in the future
•Abate the adverse environmental impacts from contaminated land
•Allow for the safe reuse of contaminated land

The first policy is intended to include avoiding the creation of wastes; taking long term after-use of disposal sites into account from the outset, and giving due consideration to the location and operation of industrial plants to avoid contamination. The second policy covers the need to carry out remedial actions on sites once identified. The third covers a need to identify contaminated sites and to control their use if the contaminants are not removed or rendered harmless.

INDIVIDUAL PROJECTS

The sections below are intended to highlight some of the important conclusions and more promising prospects.

Long Term Effectiveness

This Project provided the basis of the discussion above. In addition to a discussion of the philosophical and technical aspects of long term effectiveness of remedial measures in general, a detailed assessment was made of each of the remedial measures discussed in other parts of the report in terms of the opportunities they provide for permanent or long term solutions. A review was also made of the methods available for assessing the performance of remedial measures.

On-site Processes

In on-site treatment, the contaminated soil is excavated, cleaned up in some way and then re-deposited. In principle, there are several different procedures which might be used: extraction, thermal treatment, chemical treatment, mechanical and physical separation, steam-stripping, microbiological treatment, stabilization and flotation.

On-site treatment processes, with the exception of those involving stabilization, are designed to provide a final solution. In general, they will rely on the application of established technology from the fields of chemical engineering, hazardous waste treatment and mineral processing. The prospects from a technical viewpoint are promising. Some processes involving thermal treatment and separation have already been applied successfully, and others are at an advanced stage of development. In the medium term, microbiological treatment systems look promising.

The Dutch government has chosen on-site treatment and the comparable concept of soil treatment at a central processing plant as the best long term option for dealing with contaminated sites in the Netherlands. It is encouraging the development of the necessary technology by direct funding of research and development and by funding of reclamation projects, some of which are used to demonstrate and evaluate new methods and processes.[8]

In Situ Treatment

In situ treatment of contaminated land in which the contaminated ground is treated without excavation offers a number of attractive options for: (1) removal or destruction of contaminants, (2) stabilization of the contamination and (3) solidification to achieve some engineering objective such as improved ground stability. Two main treatment methods are possible:
•Surface application of treatment agent
•In-ground injection of treatment agent

The latter is analogous to the well-established engineering practice of grouting which is one option.

The major technical difficulties are: (1) how to ensure intimate contact between treatment agent and contamination which is compounded by the inherent chemical and physical heterogeneity of many contaminated sites, (2) possible unwanted interactions between treatment agents and contaminants, (3) difficulties in ensuring that treatment has been fully effective, (4) difficulties in applying injection techniques at depths of less than about 2 m and (5) production in many cases of a liquid waste stream requiring treatment.

There have been few successful applications of in situ treatments, and there are significant difficulties to be overcome. Nevertheless, some interesting and promising developments are taking place. As in situ treatment concepts can, in many cases, offer the possibility of permanent solutions, it would be worthwhile persevering with research and development in this area. Microbiological treatment systems seem to have considerable potential. Electro-osmotic techniques and thermal treatment by electrical heating also merit further investigation.

Barrier Systems and Hydraulic Measures

At present, in most countries, attempts to solve a "contaminant" problem are likely to involve cover, barriers and hydraulic measures with provisions for treatment of groundwater and leachate. Such measures may, in any case, be required to supplement on-site and in situ treatment processes. Long term effectiveness is of paramount importance for such remedial measures. The designer has to consider the likely installed effectiveness of each component of the scheme, its interaction with other components, the effectiveness of the scheme overall and any changes that may occur with time. This concept requires a systematic analysis with an identification of risks (to the system) and their quantification where possible (e.g., 1 in 100 years rainfall events are commonly taken into account in the design of drainage/sewerage schemes). This process is analogous to any major engineering design project. The design analysis may be aided by the use of modelling of groundwater and contaminant movement including the effects of barrier and hydraulic systems.

The performance of covering systems is particularly time-dependent. The component parts of the system and contamination may change with time, and the environmental stress on the system may also increase. Vegetation growth can be both beneficial and detrimental; for example, increased cover will reduce erosion but root growth may lead to penetration of synthetic barriers and to uptake of toxic elements. Synthetic materials are likely to deteriorate with time.

Vertical barriers to control the movement of groundwater and contamination can be installed using well-established engineering procedures including slurry trenches, diaphragm piling and grout curtains. Such barriers will always permit passage of some waste or other fluids, either because the permeability, although very low, is nevertheless finite or because of unavoidable imperfections in installation. There are, however, doubts concerning vertical barriers' long term effectiveness as a means of controlling contamination owing to possible adverse interaction of barrier materials with contaminants and the possibility of breaches either induced by nature (e.g., tree roots) or by man (e.g., subsequent excavation). Horizontal barriers can be installed by means of a number of ground injection/grouting techniques, but these techniques are not well-established or proven. These also are susceptible to adverse interactions with contaminants.

While there is a shortage of information on the long term effectiveness of containment (macro-encapsulation) systems, the prospects are improving. The construction of vertical barriers is a well-established engineering technique, the potential limitations with interactions with regard to contaminants have been recognized and work is in progress to produce improved systems. Similarly, the multi-functional nature of most covering systems has now been recognized and their design is progressively on a more rational basis.[9] Thus, while containment with associated hydraulic measures may not provide a permanent solution, it can often provide a solution that is likely to remain effective for a considerable period of time. During the "breathing space" thus provided, the hazard presented by the contaminants may be reduced by natural processes and new forms of permanent treatment may be developed.

Groundwater Management and Treatment

In this project, the investigators examined conditions where groundwater may be, or has been, adversely influenced by migrating contaminants and the methods available to: (1) enhance the quality of the degraded groundwater by in situ treatment, (2) modify groundwater regimes and (3) treat the groundwater after extraction.

A wide range of methods is available for the treatment of contaminated water after extraction, but economic and technical viability is restricted by increasing difficulty in treating even more dilute contaminants. After treatment, the extracted water can be re-injected or discharged to surface waters. In situ treatment of groundwater suffers many of the same constraints as in situ treatment of ground including difficulty in contacting reactive agents and contaminants, uncertainty about permanence of treatment and difficulty in establishing effectiveness while it is carried out. Nevertheless, it has been successfully employed on a number of occasions, and such techniques should be further developed.

Toxic and Flammable Gases

Volatile organic compounds (VOCs) can enter the environment from many different sources by a variety of routes. Both sources and routes may differ at different stages of investigation, and remedial action and the impact may occur at significant distances (up to several kilometres) from a site. Thus, it may be difficult and expensive to identify all environmental impacts and, conversely, it may be difficult to link an overt health or environmental impact to a source.

The potential long term environmental impact of VOCs and ways of controlling their emissions from sites requires further investigation. Current dispersion models do not always give reliable predictions of contaminant movement.

Rapid Methods of On-site Analysis

In the case of VOCs and other gaseous contaminants, field measurements are essential. The project on rapid methods of on-site chemical analysis dealt only with U.S. experience. Information was sought from other countries, but little was forthcoming reflecting the different scale and nature of the problems in the different countries.

Iron and Steel Making Sites

The social consequences that result from a large-scale run-down of an industry such as the iron and steel industry make it imperative that the land is brought back into beneficial use. The elimination of an immediate environmental impact is not enough; the land has to be restored in a way which requires only minimal long term attention.

The steel industry was selected because of the rapid reduction in its size owing to improved productivity, the effects of the present world recession and increased pressure from imports from new producer countries. In addition, much information relevant to coking plants is already available in the audits made of the problems presented by coal carbonization and similar sites.[10] The size of the potential problem can be seen in the 1980 contrast between production and capacity in the EEC countries: 128 vs 202 M tonnes.

Generalizations about iron and steel making operations are difficult because of the many technical changes that have occurred in the industry. Location, age and integral complexity all have to be considered. However, they all have in common, albeit to varying degrees, a number of potential problems in terms of contamination or engineering factors affecting redevelopment. Their importance depends upon a number of site-specific factors including intended site use.

The principal problems include chemical contamination in the coking plant area, pickling plant, ore and waste disposal areas such as lagoons and slag heaps, large deposits of old physically and chemically unstable slag, massive foundations and the presence of underground workings and mineshafts when plants are located in mining areas.

CONCLUSIONS

A study such as this cannot, by itself, produce new solutions to the technical problems presented by contamination. Nevertheless, the Study Group believes that its report will help in four ways by:

- Promoting an awareness of the need to consider the long term effectiveness of remedial measures and by providing a philosophical and technical framework within which they may be judged
- Illuminating some of the interactions that must be taken into account
- Drawing attention to progress in developing permanent and long term effective remedial measures
- Encouraging continued information and technology exchange between countries, organizations and technical experts

The assessment and treatment of contaminated land are quickly developing subject areas of increasing interest in each of the participant countries. Thus, during the course of the study, a number of guidance manuals or handbooks have been produced and national conferences held. In general, the handbooks, like the CCMS study, are based on desk reviews of the existing technology with only limited input from practical use. If the Study Group's recommendation concerning the need for detailed long term evaluation of remedial measures is accepted by responsible authorities, then the technical basis of such guidance documents should improve in future years.

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DESECRATION AND RESTORATION OF THE LOWER SWANSEA VALLEY

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INTRODUCTION

The 480 ha of industrial dereliction in the Lower Swansea Valley resulted from almost 250 years of smelting and processing metals. At different times, copper, lead, silver, arsenic and zinc were smelted in 22 plants along the tidal reach of the River Tawe. Later, ten steel and tinplate operations were established further inland (Fig. 1). Up to 1924, the non-ferrous metals were most important with two-thirds of the copper imported into Britain being smelted in this one area. Copper smelting declined after 1880 and was replaced by zinc. After 1928, steel and tinplate assumed a dominating position in the industry of the valley with four out of every five British tinplate workers employed within twenty miles of Swansea. The legacy of dereliction included virtually all the characteristic features such as the 7,000,000 tons of slag, ruined buildings, restricted access and unvegetated, contaminated, eroded soils of the valley side (Figs. 2 and 3).

The Lower Swansea Valley Project was set up in 1961 with the financial assistance of the Nuffield Trust, Swansea County Borough Council, the Welsh Office and the University College of Swansea. The brief of the project was "...to investigate the physical, social and economic situation in the Lower Swansea Valley, to understand the reasons which had inhibited its development in the past and to provide the information necessary for its future development." The project was clearly seen as the first stage in which information was to be gathered and interpreted, leading eventually to the renewal of the devastated land and development of new forms of land use. The work of the Lower Swansea Valley Project is summarized in a final report.[1]

INVESTIGATION OF THE PHYSICAL ENVIRONMENT

Existing plans of the Ordnance Survey had insufficient detail for the base work of the project. Aerial photography of the valley was flown in June 1962 and a detailed map compiled by photogrammerty at a scale of 1:5000. A contour interval of 10 ft up to 200 ft OD was adopted with a 20 ft interval above that level. So that the position of former smelting works could be accurately located, information available on the existing 1:1250 Ordnance Survey plans was superimposed on to the photogrammetric map. The availability of a correct detailed base map enabled calculations to be made of the area and volume of the many tip complexes. To assist this work and the subsequent geological, ecological, pedological and hydrological contributions, the project area was subdivided into plots where common problems occurred. These plots have subsequently formed the basis of the reclamation plans.
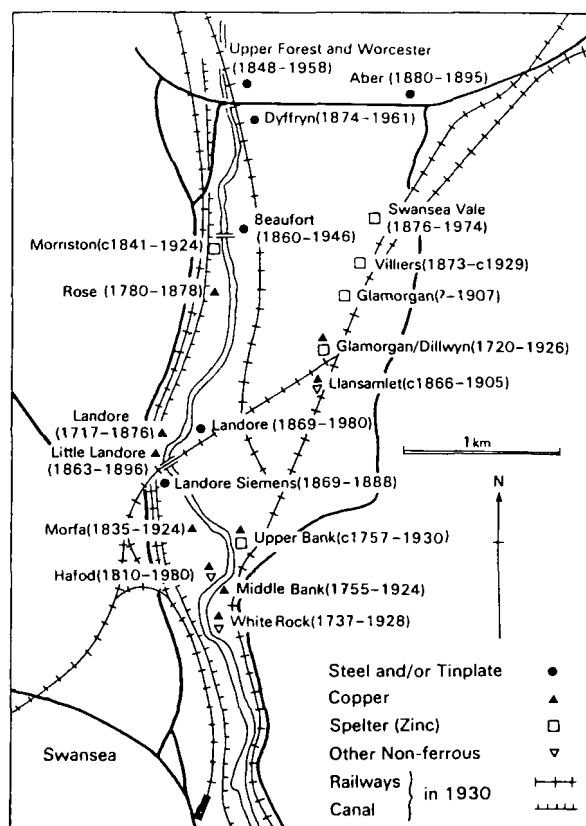
Figure 1
Metalliferous Works in the Lower Swansea Valley

In the early 1960s it was thought too expensive to remove the many slag heaps, so experimental work began to find how plants might be encouraged to grow in the inhospitable environment of metalliferous wastes. If a satisfactory cover of plants could mantle the tips, this would be a relatively inexpensive way of improving the visual appearance of the valley.[2] The use of amendments such as sewage sludge, domestic refuse, pulverised fuel ash and inorganic fertilizers was investigated in a series of field and plot experiments with mustard, common bent grass and a grass ley mixture. This work was essentially empirical as little was known at that time of the physico-chemical factors which controlled the availability and
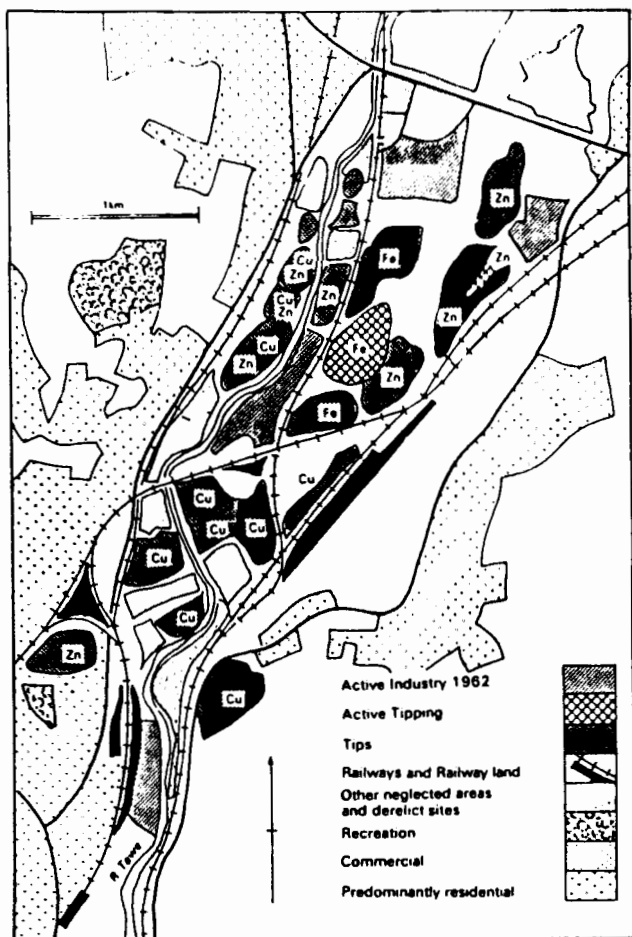
Figure 2
Metalliferous Wastes in the Lower Swansea Valley

the soil respiration suggested that the inhibition of soil-living microorganisms was more through lack of organic matter than metal toxicity.

A survey of plant species growing naturally upon the various tip materials in the Lower Swansea Valley was made. The percentage of ground covered and the number of species occurring in quadrats on the surface of the tips gave the following results:

	Zinc Waste	Copper Waste	Steel Waste
% of ground covered including mosses	10	27	16
% of ground covered excluding mosses	1	4	3
Total no. species recorded	4	15	36
No. of quadrats	50	57	70
Ave. no. per quadrat	0.04	1.5	3.2

(After Weston et al.[5])

A sparse cover of common bent grass (*Agrostis tenuis*) and wavy hair grass (*Deschampsia flexuosa*) occurred upon the exposed, stony subsoil material of the eroded soils surrounding the smelters[4] (Fig. 3).

A major emphasis originally in the Lower Swansea Valley Project was to improve the physical appearance of the environment by tree planting in these eroded natural soils. After liming and some fertilizing to encourage rooting, Japanese larch, Lodgepole pine and birch were planted from 1963 onwards. In the decade 1963-73, over 100,000 trees on 37 ha were planted at minimal cost with volunteer labor and trees provided by finance from the City Council and the Welsh Office. These trees now make a major contribution to the improved appearance of the valley. (Certain areas were

uptake of heavy metals by plants growing in toxic tip material. The best results were achieved on the steel wastes and poorest growth occurred on zinc waste with copper showing an intermediate response.[3]

Trials of different species of shrub were undertaken to ascertain whether their growth would be satisfactory, with appropriate encouragement, to cover tips. Plants which were known to be tolerant of acid conditions, atmospheric pollution, drought and exposure were chosen. Some of these plants are natural colonizers of derelict areas, and some are nitrogen-fixers. They include *Ligustrum vulgare, Buddleja davidii, Hippophae rhamnoides, Rhododendron ponticum, Salix repens, Clematis vitalba, Lupnius arboreus, Robinia pseudoacacia, Sorbus aucuparia, Thelycrania sanguinea, Alnus glutinosa, Betula verrucosa, Medicago* (innoculated with *Rhizobium* sp) and *Tagetes minuta* and were grown in experimental areas on copper, steel and zinc waste tips.

In parallel with this work, plant species were collected from soils known to be rich in copper, lead or zinc in which a natural tolerance to heavy metal levels higher than normal had evolved. By cultivation and seed collection it was hoped to obtain tolerant clones of plants in sufficient amounts to use in revegetation. Although this aspect of the work showed promise, it was not possible to follow it through during the period of the project; subsequently the National Seed Development Organization did produce the lead-zinc tolerant variety of *Festuca rubra* known as "merlin".

The microbiology of the three main tip types in the Lower Swansea Valley was investigated using the microbial colonization of cellulose film and dilution plates with a variety of cultural media. Bacteria of several different groups were isolated, but the nitrogen-fixing *Azotobacter* was not detected. Mycorrhizal fungi were absent from the surface materials of the tips. Investitations of

Figure 3
Soil and Gully Erosion in the Lower Swansea Valley

planted with grasses but with less success.) Since 1973, emphasis has been on landscaping funded by grants from the European Regional Development Fund as part of the infrastructure development, with the major restoration being paid for by the Welsh Development Agency from government funds.

SOCIAL ASPECTS

Investigations of the human environment played a significant role in the initial research. A transportation study found that the valley floor was almost totally devoid of roads with large areas only accessible on foot. The River Tawe formed a barrier along the western side of the project area, and the presence of railways and disused canals broke the land into a number of small awkwardly shaped areas (Fig. 2). The recommendations for a new road network for the valley included a spine road to serve all the northern part of the project area, a new crossing of the River Tawe in the Hafod-Pentre Chwyth region and improvements to the roads on both sides of the valley. The route of the western road improvement should follow the line of the Swansea Canal to bypass Morriston.

The social survey of the valley and surrounding districts examined the distribution of population according to sex, marital status, occupational status, educational attainment, income, children in receipt of free school meals, children taken into care and juvenile delinquency. The housing stock was found to be old and in need of replacement or renewal. Schools and other public buildings were inferior to those found elsewhere in the town. There was a shortage of public open space, and it was recommended that this should be taken into consideration in the preparation of the development plan. Some improvements of the roads took place, but otherwise no obvious results followed from the social surveys. However, one of the most significant features of the development plans drawn up by the Swansea City Planning Department is the "park" concept which goes a long way to meeting the earlier proposals for public open space in the valley. One such park is the Leisure Park occupying land south of the main railway line with facilities for informal activity and organized sport.
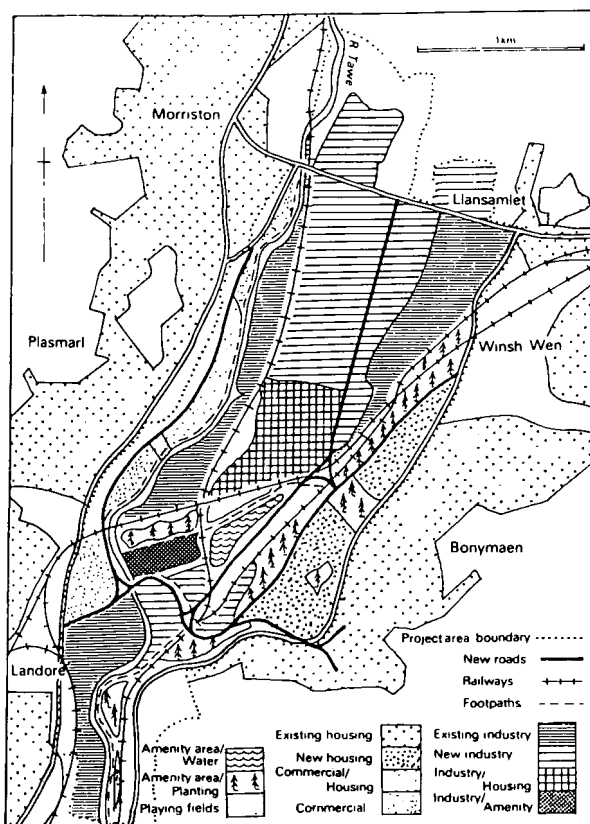
Figure 4
Land Use Proposals in the Lower Swansea Valley Project Report

The Lower Swansea Valley Project was unique in many ways as it was the first thorough investigation in Britain of the reasons for dereliction and its persistence. The project brought together people from many disciplines who contributed skills to unravel the history of dereliction and to establish a wealth of data on the physical environment and human attitudes to it. The assembly of this material enabled a draft plan to be suggested for the redevelopment of the valley (Fig. 4).

The opportunity to assess the success of the Lower Swansea Valley Project came in 1979, when a conference was held to review progress and to encourage the completion of the task of rehabilitation of the valley.[5] Although weighted strongly in favor of planning and social studies, this conference indicated that research work into the environmental background was continuing but at a lower intensity.[6,7] Swansea City Council had commissioned studies on the River Tawe, the extension of Pluck Lake as an amenity feature and on basic development plans. Further aerial surveys were flown in 1969 and 1982. With the announcement of the Enterprise Zone in 1980, investigations of bearing capacity of certain sites for industrial development have been undertaken specifically with the aim of providing information for prospective site occupiers.

In retrospect, the most successful part of the Project has been the tree planting which has transformed the appearance of the valley over the past twenty years. The experimental work to try to grow plants on inhospitable tips was of academic interest, but the findings were not to solve the problem. Investigative work for the project gave an opportunity for training to several of the leading figures in land restoration in Britain today.

RECLAMATION

Plans for Swansea after the Second World War had envisaged a predominantly industrial future for the valley, at a time when the major industrial concerns were still active in the valley. Events overtook this plan of 1960, and the findings of the project were incorporated in a 1968 Draft Development Plan which made improvement of the River Tawe a major feature. This, too, was changed by a 1974 consultants' report which recommended a mixture of industrial and leisure activities accompanied by landscape improvement in a phased development. After local government reorganization in 1974, the new City Council published an Interim Planning Statement for the valley which included a "Forest Park" and a "Riverside Park," reflecting a more social attitude to planning. These ideas eventually grew into the "Five Park Scheme," in which the Enterprise Zone, designated by the government in 1980, became the Enterprise Park for industrial activity, accompanied by a Leisure Park, a Riverside Park and, in the old dockland area, a City Park and a Maritime Park (Fig. 5). Thus the concept of restoration of the Lower Swansea Valley has taken place within a wider framework of urban renaissance than originally anticipated by the pioneers of the Lower Swansea Valley Project.

Although small areas had been restored, no significant reclamation took place until government assistance became available in 1966. Since that date, reclamation has been active every year, culminating in the last major scheme which began in 1983. The reorganization of local government in 1974 gave fresh impetus to the process of restoration as the new Swansea City Council gave priority to the work. A small executive committee was set up with power to take decisions without going through the normal lengthy channels. As a result, full advantage has been taken of any financial aid, with the City Council able to respond rapidly and positively to any opportunities for redevelopment.

The rate of reclamation was controlled by the speed of land acquisition by the City Council as the Welsh Development Agency would only accept grant applications for land which was in public ownership. All the land recommended by the 1967 Report has now been acquired by the City Council. One advantage of the publication of the earlier report was that land owners accepted the value of unified ownership for redevelopment purposes. Reclamation began with sites on the periphery of the valley, where there was access for heavy machinery, and gradually worked toward the center of the
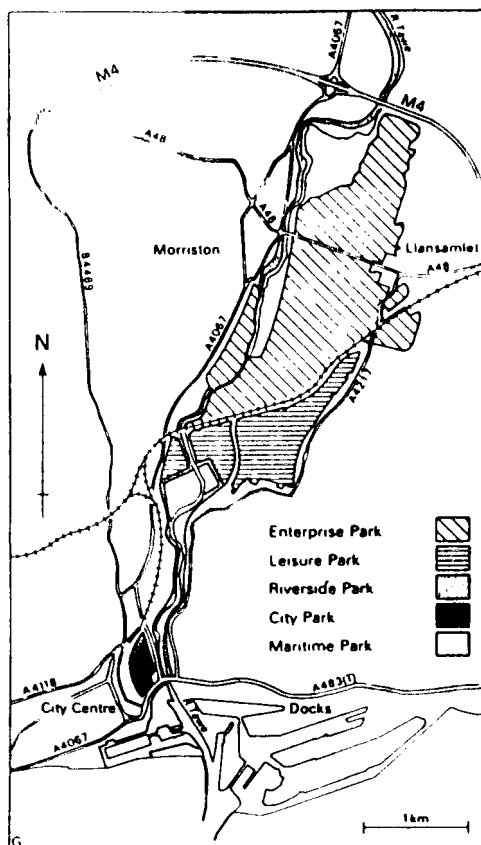
Figure 5
Swansea City Council's Five Parks Scheme
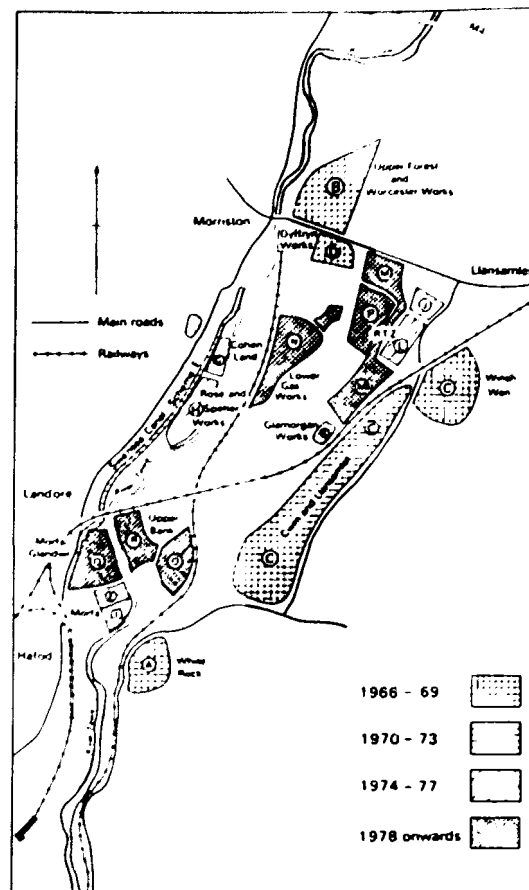
Figure 6
Reclamation Schemes in the Lower Swansea Valley, 1966-1982

Table 1
Reclamation Schemes in the Lower Swansea Valley, 1966-1982
(Bromley and Morgan, 1983)

MAP CODE a	NAME OF SCHEME	LOC b	AREA ha	DATES OF WORK Start	DATES OF WORK Finish	COST c	BUDGET YEAR	LAB d	GRANT e
A	White Rock	S	33	1967	Nov 1968	£113,917 P	67/68 68/69	C	85% from Welsh Office
B	Upper Forest and Worcester Works Phase I (Clearance)	EZ	16	April 1967	Dec 1967	£86,391 C	67/68	C	85% from Welsh Office
	Phase II (Filling. Borrow from White Rock)			1968	Dec 1968	£21,141 D	68/69	C	" " "
C	Cwm, Winsh Wen and Llansamlet	EZ	104	Jan 1969	Jan 1970	£30,447 E	69/70 70/71	C	85% from Welsh Office
D	Dyffryn Works	EZ	8	Oct 1969	July 1970	£110,749 E	69/70 70/71	C	£59,272 from Welsh Office
E	Swansea Canal Phase I (Drainage)	N and S	11	Aug 1970	Dec 1971	£30,172 E	70/71 71/72	C	85% from Welsh Office
E F	Swansea Canal Phase II (Filling) Morfa I (Borrow for Swansea Canal)	N and S	4	Nov 1970	Dec 1971	£131,694 E	70/71 71/72	C	£90,189 from Welsh Office and £20,000 from British Waterways Board

Table 1 (continued)

MAP CODE a	NAME OF SCHEME	LOC b	AREA ha	DATES OF WORK Start	Finish	COST c	BUDGET YEAR	LAB d	GRANT e
G	Plasmarl: Cohen Land and Graig Brickworks (Outside LSV)	N	3	Feb 1972	Feb 1974	£21,637 E	71/72 72/73 73/74	C	£4,717 from Welsh Office
H	Rose and Spelter Works	EZ	16	Feb 1974	Mar 1975	£105,455 T	73/74 74/75	C	—
I	Morfa II	S	2	June 1974	Jan 1975	£110,204 E	74/75	C	£13,044 from Welsh Office (LEA)
J	RTZ I	EZ	3.5	Oct 1974	June 1975	£58,084 T	74/75 75/76	C	—
K	Glamorgan Works	EZ	0.5	April 1975	June 1975	£4,845 E	75/76	C	—
L	RTZ II (including construction of culvert costing c. £53,000)	EZ	5.5	Nov 1976	Sept 1977	£193,321 E £122,555 £70,766	76/77 77/78	C	100% from WDA
M	RTZ III and IV Phase I	EZ	24.5	April 1978	Dec 1979	£271,619 E £268,300 £3,319	78/79 79/80	C	100% from WDA
N	Morriston Lower Gas Works	EZ	13	Oct 1978	Mar 1980	£173,266 E £112,200 £61,066	78/79 79/80	C	100% from WDA
O	Upper Bank Phase I (Reclamation and laying sewer prior to construction of Athletics track)	S	8.5	Feb 1980	May 1980	£70,000 E	79/80 80/81	C	100% from WDA
	Winsh Wen Earth-Works (Site preparations not derelict land)	EZ		May 1980	Oct 1981 and after	£135,000 E	80/81 81/82	D	£40,500 from ERDF
P	RTZ III and IV Phase II (Reclamation of Site 6 and culvert on Site 4)	EZ	8.3	Oct 1980	April 1982	£502,000 E £283,000 £219,000	80/81 81/82	C	100% from WDA
Q	Glandwr/Morfa (Borrow for Site 6 reclamation) NB Frederick Place also borrowsite for Site 6	S	10.4	Oct 1980	April 1982				

Table 1 (continued)

MAP CODE a	NAME OF SCHEME	LOC b	AREA ha	DATES OF WORK Start	DATES OF WORK Finish	COST c	BUDGET YEAR	LAB d	GRANT e
R	Upper Bank Phase II (Some borrow for Site 6)	S	15	Nov 1981	April 1982	£237,811 E (up to Aug 1982)	81/82 82/83		100% from WDA
S	Site 8c and Site 14	EZ		Jan 1982	March 1982	£7,031 E	81/82	C	100% from WDA

NOTES:
a. See Figure 9
b. EZ = Enterprize Zone
   N = Northern LSV outside EZ
   S = Southern LSV
c. The total cost for each scheme is the first figure specified. Where possible the costs are allocated to particular budget years using the SCB and SCC Annual Budgets. Except for scheme R, the costs are for the period prior to 31 March 1982. The sources of information are:
   C. PGPC 7 December 1967
   D. PGPC 6 January 1969
   E. SCC, Engineer's Department
   P. SCC, Planning Department
   T. SCC, Treasurer's Department

d. C = Contract Labor
   D = Direct Labor
e. The amount of grant specified is the amount awarded up to 31 March 1982
SOURCES:
   SCC, Engineer's, Planning and Treasurer's Department; PGPC, PC and PRC minutes
1 £ = $1.30 (US)

derelict area. The sequence of reclamation schemes is given in Table 1 and Figure 6, the work being done under contract by outside contractors but administered and supervised by the City Council Engineering Department. Schemes have been initiated only when financial assistance has been assured and the progress reflects the provision of government funds.[8]

It is difficult to specify the exact cost of a reclamation scheme. The costs listed in Table 1 are those for reclamation alone. They do not include the preliminary cost of the land purchase, the costs of administration and design or the subsequent landscaping expenses.

The cost of reclamation schemes in the Lower Swansea Valley reflects the quantity and character of the material that needs to be removed or remolded. These factors and the variety of physical problems presented by the industrial wastes and derelict buildings have been summarized by the City Engineer.[9] The toxic character of much of the tip material has been a particular problem.[10] The discovery of unforeseen obstacles has often resulted in increased costs, such as the exposure of a brick-work culvert during reclamation of the Rio Tinto Zinc site. Changes in policy regarding the subsequent use of the reclaimed land, and hence changes in the gradients of slopes required, have also led to increased costs. The initial tender of £106,736 for clearance at the Rio Tinto Zinc site was considerably below the final cost of the scheme, because an additional £30,000 was required for regrading alone. Frequently, it is not until clearance is actually underway that the final decisions are made on the required gradients at a particular site.

The costs of reclamation schemes have been reduced by the presence of recoverable materials on the clearance sites, and by undertaking schemes as combined projects. The Glamorgan works' site, for example, included slates and stone of value to the contractor, and the existence of those materials reduced the cost of the contract. Other schemes have produced usable hard-core. Schemes conducted as combined projects have involved one site providing fill for another. Thus, material from the Rose Spelter works' site helped to raise the level of an adjacent site (Items G and H, Table 1). When the reclamation is completed, the sites often have considerable value for industrial development; this not only has reduced the need and eligibility for a grant in some cases (as at Rose Spelter works) but also has yielded occasional revenue from land sales.

Schemes have usually been initiated only when financial assistance has been ensured so that the speed of reclamation has reflected the availability of government funds. The schemes of the late 1960s, when Welsh Office grants first became available, resulted in the reclamation of 161 ha of land. The reclamation of the White Rock tip involved work outside the valley floor, but is included in Table 1 because material from it was used to raise the

level of the Upper Forest and Worcester works' site before construction of the Morganite factory. In the first four years of the 1970s, only 18 ha were reclaimed; progress quickened in the second half of the decade.
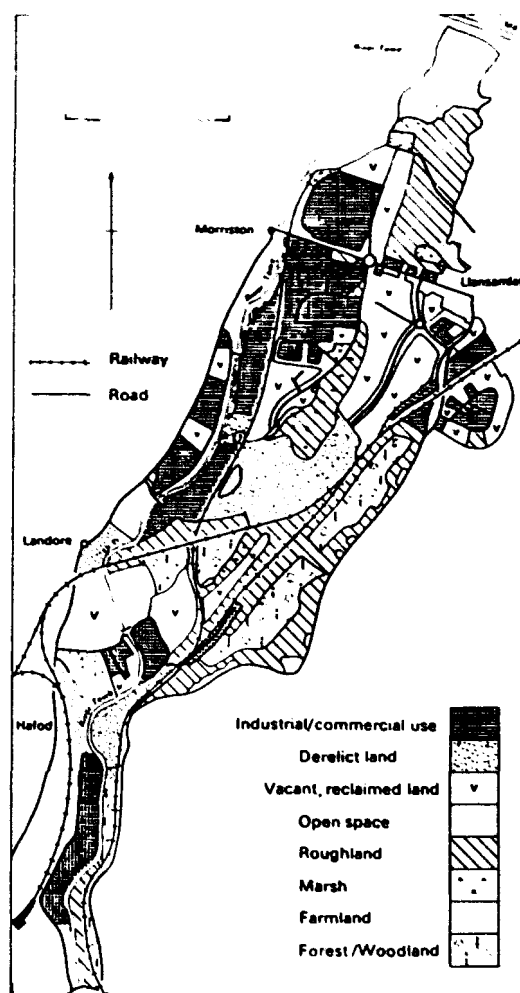
Figure 7
Land Use in the Lower Swansea Valley, 1982

The interest of prospective developers has had a less significant impact on the sequence of reclamation schemes, and most schemes have been undertaken without a particular developer in view. However, the clearance and subsequent raising of the Upper Forest and Worcester works' site was effected with the Morganite factory as the expected after-use. Site preparation at the Winsh Wen site was effected during late 1980 and early 1981 in order to make several hectares of industrial land ready for the Enterprise Zone.

The toxic wastes have been dealt with by encapsulation to avoid the removal of large quantities of material out of and into the valley, and the more benign steel waste material has been used to transform the central part of the valley into a fresh landform upon which factory units can be established. The present pattern of land use is shown in Figure 7.

From inception to completion, the restoration of the valley has taken 25 years. Most of the scars of former dereliction have now been removed, but shortage of suitable covering materials means some areas of copper slag are still to be covered; excavations for an amenity lake are also in progress. Physical restoration may have taken place but, despite government assistance, the economic resuscitation of the valley is accomplished slowly at a time of national and worldwide recession.

ACKNOWLEDGEMENTS

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INVESTIGATION OF LAND AT THAMESMEAD AND ASSESSMENT OF REMEDIAL MEASURES TO BRING CONTAMINATED SITES INTO BENEFICIAL USE

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INTRODUCTION

In the mid-1960s, more than 1,000 acres of land (a major part of the Royal Arsenal in Woolwich) were obtained from the Ministry of Defence by the Greater London Council for redevelopment. At that time, it was the biggest single area of vacant land in London. With other land at nearby Abbey Wood, the acquisition provided an opportunity for creation of the new community of Thamesmead.

For more than 200 years, the western end of the site was subject to intensive use for the manufacture of armaments. With the growth of technology, an expansion of industrial activity took place, reaching its peak in the war of 1914-18. Expansion took place eastwards along the Thames: as output increased, vast quantities of waste were generated by industrial processes, manufacture of town gas, generation of electricity and the testing of explosives.

Large mounds were deliberately created from waste to form cover for sensitive installations, and marshland was filled with industrial residues to provide foundations for buildings and a network of rail tracks and roads. Following the end of the Second World War, marked by the destruction by burning of great quantities of surplus explosives and disposal of bomb damage rubble, the installations gradually fell out of use, leaving a legacy of dereliction that provided only little evidence of a new and potentially hazardous environmental problem.

Throughout the older districts of Greater London, the industrial contamination of land emerged as a form of pollution not previously seen as a major cause of concern. However, with demand for inner city development land coinciding with the decay of traditional industries, it followed that housing and schools would have to be built on land not previously considered for such use. The condition of ex-industrial land has demanded careful examination before redevelopment, and the Royal Arsenal lands are no exception.

A multi-disciplinary team was assembled to investigate the problem of contaminated land at Thamesmead, and their work continues. The team's work is part of a comprehensive approach to reclamation which includes the creation of new land by controlled deposit of contaminated material and the profitable recycling of surplus excavated materials from elsewhere.

THAMESMEAD SITE

The development area of Thamesmead is 16 km from the center of London. It covers approximately 650 ha and is situated on the South Bank of the Thames with a 5.5 km frontage to the river. The land is composed almost entirely of drained marsh at the foot of rising parkland which forms a backdrop to the initial stages of new development.

Much of the land developed to date has no known history of industrial usage and has not been subject to contamination. The remainder, which formed a major part of the Royal Arsenal, is 400 ha at the North of a raised embankment containing the London Southern Outfall.

Ground Conditions and Drainage

The ground is composed of silty clay up to 1.5 m thick overlying peat and alluvium 5 to 7 m deep. At the base of the alluvium is a stratum of water bearing gravel on Thanet sand and chalk.

The site forms a natural drainage basin between the Thomas and the Wickham Valley which lies at the base of the rising ground to the South. Historically, surface water run-off from the hills drained into the area by way of culverts; after flowing naturally across the site through a network of ditches, the water was discharged into the Thames via tidal sluices. Typical of marshland, the site is flat and naturally featureless except for trees.

The high water table and poor load bearing capacity of the ground require that all construction work be piled or surcharged. The filling of undrained marsh in earlier times has led to many of the present pollution problems due to the industrial origin of the materials used for reclamation.

INDUSTRIAL HISTORY

The original river bank was probably built up by the Romans, and there is evidence of a settlement at nearby Plumstead. In the 12th century, an Augustinian Abbey was established on the rising land to the South. From that time until 1524, the monks from Lesnes played a part in reclaiming and draining the land.

Following a period of neglect during which severe flooding was experienced, the responsibility for maintaining the river wall and draining the marshes passed to Commissioners for Sewers in about 1600. During the reign of Henry VIII, industrial development of the area was foreshadowed by the establishment of the Woolwich Naval Dockyard. Downstream, land destined to become part of Thamesmead known as "The Warren" became a naval and military center in the 17th century when Ranges were established and storehouses for guns were built.

The earliest major manufacturing industry in this area started with construction of a brass foundry by Sir John Vanbrugh in 1716 when the first cannon were cast. The output of the foundry grew, and the Royal Regiment of Artillery moved its barracks to Woolwich in 1719 to be near its main source of supply. The Royal Artillery depot remains in Woolwich to this day, as does the original brass foundry which has been preserved as a building of historic interest.

Land was reclaimed from the marshes as the establishment grew, and land filling became an occupation of convicts held in prison hulks anchored in the river adjacent to The Warren. Mud and debris from the construction of St. Katherines Dock near the Tower of London was taken to the site for filling purposes, and this material was heavily augmented by waste products from the gun foundry and other industrial installations. By the 19th century, The Warren had been renamed "The Royal Arsenal." and a period of major expansion began. By 1890, the Arsenal covered 324 ha which included practice and experimental ranges. A further 160 ha of marsh were added at this time and 11 moated magazines were constructed, some of which are now being preserved for their amenity value.

Manufacture or heavy weapons, ammunition and explosive devices reached its height in the war of 1914-18 when some 80,000 people were employed in armaments work. Coal and raw materials entered the area via a spur from the adjacent railway, by barges into the Arsenal dock or by ships using piers to deep water in the river.

The Arsenal was self supporting as it produced its own town gas (from about 1850); later, a steam plant and electric generating station were added to the facilities. The prodigious quantities of ash and waste produced by these plants alone, over their long life, have remained to make their contribution to the topography of the land and the problem of contamination.

The arsenal continued with production and testing of modern armaments through the war of 1939-45 when it proved to be vulnerable to air attack. A large number of bombs fell on the area, and over 1,000 people lost their lives. After the war, vast quantities of surplus explosives were destroyed on the site by burning; the products of the burning added to the growing quantities of waste material from industrial/experimental processes and debris from destruction of obsolete installations.

The area finally was sold to the GLC; it was handed over in stages during the 1960s. Withe the demolition of remaining buildings, the stage was set for the development of Thamesmead, which at that time was proposed to be a town for 60,000 people.

THE DISCOVERY OF INDUSTRIAL CONTAMINATION

Development of Thamesmead started in an area to the south of the Arsenal boundary, and it was some time before work of any magnitude began on land where there had been any concentrated industrial activity. Not until 1975 was the extent of industrial contamination fully revealed, although its presence had been suspected for some time. The initial impact on site development was spectacular, because the discovery of heavily contaminated material during excavation work was accompanied by a chemical fire and the penetration of buried tanks containing liquid residues from the former gas works.

The situation was considered sufficiently serious to suspend construction operations to avoid risk to personnel. The financial penalty for stopping the contract prompted a project-wide inquiry which indicated that all land used by the Arsenal must be thoroughly examined. Hazards to health had to be assessed and means of providing protection had to be determined, both for the workforce and for eventual users of the land.

Significantly, the problems at Thamesmead began to emerge at a time when similar difficulties were being encountered by the Council on other sites in London and by other development authorities elsewhere.

BACKGROUND TO THE INVESTIGATION

The working party of officers established to investigate and deal with the problem were faced with a number of difficulties, not least of which was the obviously diverse but classified nature of former industrial activity. Buildings housing industrial processes had been constructed on marshland reclaimed with industrial waste and other fill materials of unknown origin. Furthermore, the practice of using industrial waste for foundations to the Arsenal network of railway lines, vehicle tracks and as protective cover to sensitive installations led to a land make-up of some complexity.

Use of rubble from bombed buildings in East London as backing to the river wall was not necessarily a cause for concern, but waste disposal from the Arsenal at the same time and in the same locations led to random localized filling patterns.

Destruction by burning of war surplus explosives, incendiary devices and other dangerous material on areas of unused marsh and industrial waste sites again tended to complicate the investigation.

In contrast to the mixed and apparently serious contamination which was sometimes evidenced by severe distress to vegetation, the Eastern sector of the site was typical of pastureland on drained marsh supporting a healthy plant growth and habitat for wild life.

Conversely, it became clear that isolated areas of severe contamination existed in the generally clean, Eastern part of the Arsenal, while in the heavily industrialized West and Central parts there remained zones of thickly wooded clean land.

SCOPE OF THE INVESTIGATION

The complexity of land use and random disposal of waste necessitated a total examination of the site previously occupied by the Royal Arsenal. Apparently clean areas would also be subject to investigation as there was evidence to suggest that a seemingly undisturbed ground surface was not a reliable indication of contamination-free conditions beneath.

The determination of site specific sampling strategies depended very largely on the following:
•Such history of the site to be tested as is possible to collect
•A visual inspection of the ground
•Details of the intended land use

The last item intended use of the land, ultimately determines the scale of long term risk; houses with gardens being at the top of the scale. The first two items provided an indication of the condition and previous usage of the ground. Based on this initial evaluation, a sampling strategy was devised with sampling intervals which have used trial pits on 100 m centers (rarely) and as close as 10 m (center to center) where conditions are considered to be particularly bad. Usually, trial pits were excavated on a 50.0 x 25.0 m staggered grid.

As stated previously, the original use of long demolished buildings is difficult to determine, but it has been possible to identify the following activities.
•Heavy machine shop and forging work
•Non-ferrous metal foundries
•Cadmium and other metal plating
•Town gas manufacture
•Development and testing of paints
•Manufacture of acetylene
•Manufacture and testing of weapons and explosives
•Destruction of surplus explosives by burning
•Destruction of surplus incendiary devices
•Storage of coal stocks on the surface
•Dumping of industrial waste

Such activities have prompted a fairly broad spectrum of soil testing and, as investigation has progressed to suit the program of development, the list of analytical determinations has been modified by experience gained. From the outset, soil analysis has been carried out by external consultants to meet a fluctuating and often heavy laboratory workload. Determinations needed and methods of testing are specified by the Scientific Adviser to satisfy the needs of the Medical Adviser in his assessment of health hazards, and to provide data on possible deterioration of substructures.

Analytical determinations most commonly called for are indicated below, but variations are made to suit particular circumstances:
•pH
•Acid Soluble Sulphate
•Magnesium
•Elemental Sulphur
•Sulphide
•Total Cyanide
•Free and Complexed Cyanides
•Phenols
•Toluene and Cyclohexane Extractable Material
•Coal Tar and Mineral Oil
•Total and/or Available Metals: Lead, Cadmium, Mercury, Antimony, Arsenic, Zinc, Nickel, Lead, Copper

SOIL SAMPLING PROCEDURES

When the sampling strategy is agreed, the coordinator arranges the following:

- Preparation of a sampling drawing based on a 1:500 scale survey. The drawing indicates the operational grid for Thamesmead, and trial pits are related to this for ease of setting out. Each pit is given a code name reference to enable easy identification of location on-site.
- Surveyors set out the trial pits, locating each with a code-marked driven stake
- The engineer responsible for site investigation employs a contractor for excavation of trial holes by JCB backhoe excavator and provides an officer for his supervision. A scientist directs the operation and ensures that samples are taken to a set routine.
- Soil samples are taken at established vertical intervals in the trial holes usually down to 3.0 m. If deeper holes are required, a track driven excavator is employed. Bore holes are not favored unless very deep samples are required.
- Samples are placed in sealable 1 l plastic buckets identified by previously coded self-adhesive labels.
- Pre-coded log sheets are filled in as sampling proceeds, being careful to use a standard nomenclature giving the most accurate possible description of the sample including transient features such as color and smell.
- A log sheet of each trial pit is prepared describing the form and thickness of ground strata. When compared with other trial pit data, this is used to identify horizons of polluting material.
- Samples are batched and sent to a consultant analyst together with log sheets and any special instructions which the scientist deems appropriate.

WATER TESTING

The water regime at Thamesmead is complex and dynamic. The general water table is high and fluctuates due to the site being in a drainage basin. The adjacent Thomas is tidal, and the river level is often considerably higher than that of the land. There is also a "perched" water table some distance below the surface. As Thamesmead grows, the surface water drainage system is extended with the canal network, and the holding capacity of the balancing lakes is increased.

As indicated earlier, Thamesmead has been reclaimed from marshland, and successive bank raising and land drainage operations have led to the present surface water and flood control system which depends on canals, balancing lakes and tidal sluices, plus a major pumping station for emergencies. This system is being constantly extended, and undertaking general water testing at the present stage would be inconclusive, bearing in mind that a great deal of major earth moving is still to be done in both heavily contaminated and relatively clean areas. As a consequence, only routine monitoring is undertaken in situations where the public health needs of the local population have to be safeguarded. In the longer term, it is intended to complete a comprehensive survey of the complete water regime.

METHANE GAS

Methane gas generation below the surface has been a major factor in a number of development schemes on sites bordering the Thames where land has been reclaimed from the foreshore. In such cases, the generation of gas is usually associated with breakdown of organic material in river silt which has been enclosed by river wall construction and covered by landfill material. Where bodies of silt are large, generation of methane gas has been substantial, demanding expensive measures in the construction of buildings to avoid the possibility of gas accumulation and explosion.

The dominating feature of Thamesmead is the River Thames, and it has been necessary to consider the possibility of methane generation, particularly on sites close to the river wall. Fortunately, there is only one area of land where the level of methane gas has been found significant, and this has undoubtedly arisen from the enclosure of a relatively small "bay" of foreshore silt during localized bank raising in the last century.

Living accommodations are to be built on the site, and it has

been possible to make recommendations at an early stage in the design process which will enable the design of visually and functionally acceptably built structures without compromising the overriding need to avoid gas accumulation. Recommendations include the introduction of lateral dispersal arrangements using granular break layers in combination with suspended ground floors without foundation beams and, at the other extreme, the placing of all living spaces on upper floors with parking or garages on the ground.

FIBROUS ASBESTOS DEPOSITS

A search for deposits of fibrous asbestos is being carried out simultaneously with the investigation for industrial contamination. This investigation has been necessitated by the discovery of asbestos insulation on the surface, along the lines of a long removed network of overhead steam and hot water pipes which extended for several kilometers across the site from each of two boiler plants. This form of heating was necessary to avoid the risk of fire. The insulation contains both crocidolite and chrysotile and must be removed before site clearance and construction work can take place. A 10 m x 10 m search pattern is being carried out based on the 100 m operational grid. It is a tedious process for the personnel, but there is no other practical way of locating asbestos deposits in densely overgrown conditions.

Clearance of each area is undertaken by licensed contractors who originally removed the asbestos off-site to official disposal dumps. Recently, more certain methods of disposal have been put into operation at Thamesmead using on-site licensed disposal facilities.

SPONTANEOUS COMBUSTION

Foundry work, the production of town gas, generation of electricity and the generation of steam for industrial processes and district heating demanded the import of great quantities of coal. A deep water pier capable of dealing with ocean going colliers is located at the western end of the Arsenal area, and a spur from the nearby railway was used to bring in the coal from mines in Kent.

Presumably, to ensure continuity of provision during the last war, stocks of coal were held on the surface in locations behind the old river embankment. Some of the coal sank below the surface and remained after the main stockpiles were removed for normal use.

During an unusually hot and dry summer in 1976, two sites of spontaneous combustion became manifest when a belt of trees which had colonized the area died and fell to the ground as their root systems were burned away. In this case, the fires were allowed to burn through the remaining coal, but all trees and flammable materials were removed from the surface to reduce the fire loading. The fire burned out over a period of 2 yr leaving a residue of ash and debris which has since been recolonized by scrub bushes. Prior to the development which is to commence shortly, the site will be excavated down to natural clay and then filled with clean, imported granular material.

In another situation, spontaneous combustion on a raised embankment was impossible to control by conventional means. As the adjacent land was required for early development, the only economic solution was to remove the entire embankment with the fire brigade standing by to prevent spread of fire and to wet the material as it was excavated.

Both incidents proved to be valuable. Much useful data were obtained during site tests and laboratory analysis of the recovered combustible material. For guidance purposes, it has been determined that sites containing material below the surface with a calorific value of 1700 cal/g have a potential for spontaneous combustion.

SITE CONDITIONS AND REMEDIAL MEASURES

The working party of officers established to deal with land pollution at Thamesmead eventually became the Council's Assessment Panel on Contaminated Land which now has a London-wide responsibility with respect to all GLC development. The Panel is

interdepartmental and multi-disciplinary and consists mainly of officers not engaged on contaminated land full time.

The areas of professional activity covered by the members of the Panel are as follows:

•Environmental science and analytical chemistry
•Structural engineering and statutory building control
•Environmental health procedures, health and safety
•Horticulture
•Hazardous waste disposal
•Public Health Engineering
•Construction and management (coordination)

The objectives of the Panel in making their final assessment of investigation results are briefly as follows:

•To determine the condition of the site
•To identify and express the main areas of risk
•To consider and recommend remedial measures with alternative solutions if possible
•To outline minimum requirements for the protection of construction and other workers
•To determine the category of excavated material for disposal
•To initiate further inquiries if necessary on deterioration of substructures and to consider anti-explosion measures for buildings when methane is a problem
•To recommend suitable forms of landscape treatment and methods of tree preservation
•To arrange long term storage and retrieval of data from the investigation

The staff rely heavily on a detailed report prepared by the environmental scientist which includes and is based upon soil analysis, trial pit and strata logs, drawings indicating the site sampling patterns and supplementary reports on combustibility and methane generation where appropriate.

The present condition of the land is evaluated in the context of its intended development so that remedial recommendations appropriate to the proposed use can be proposed. Long term hazards to the health of land users is the primary consideration, and this sets the pattern for remedial work. Occupants of houses with gardens where fruits and vegetables may be grown are regarded to be most at risk; as the bulk of development is taken up by housing, most attention is directed to this concern.

Schools are given particular consideration, especially where there are possibilities of horticultural activity, but generally the buildings and hard play surfaces are seen to be satisfactory forms of protection in themselves. The bulk of remedial measures are, therefore, included in landscaped areas.

As indicated earlier, some sites which are grossly polluted support mature and apparently healthy trees, and where possible, these trees have been saved by a special localized technique which avoids overfilling to the point where they might die. The technique demands careful work using hand tools to remove soil from between roots and then replacement with selected material. A general covering of no greater depth than 0.2 m is applied to prevent demage and decay at the base of the tree trunk. Under no circumstance, however, would this step be undertaken in high risk areas which could not tolerate a reduction in capping depth.

The many forms of development at Thamesmead, ranging from housing to industry, demand that each site be dealt with on its merits, and experience has proved that the condition of the land is as varied as its many uses.

SHORT TERM AND INCIDENTAL RISKS

Through the Medical Advisor's Chief Environmental Health Officer, the Panel determines if there are any special requirements with respect to the health and safety of site construction personnel. Fortunately, with few exceptions, the condition of sites at Thamesmead has not prompted special needs beyond the use or ori-nasal masks and/or water spraying at most. The mandatory provisions of washing facilities and accommodation for consumption of food under the Health and Safety at Work Act for site personnel are satisfactory for the majority of sites examined so far.

Incidental risks will occur when repairs or alterations are made in the longer term to buried services. Low voltage electricity, telephone and television cables are usually buried about 0.5 m below the surface; HV cables, water and gas mains are laid with not less than 0.9 m cover; and drainage is usually deeper still.

It would be unrealistic to assume that public utility or local authorities will be kept aware of possible health risks in the longer term, so where necessary, recommendations are made for trench backfilling to take a form which reduces the risk of contact and spread of foul material over clean surfaces during reexcavation for repairs, etc. Consequently, the surplus excavated material from all trenches intended for buried services is removed from site and clean material is provided for backfilling wherever the capping layer on a reclaimed site is likely to be penetrated.

RECLAMATION

The methods of reclamation recommended by the Assessment Panel have been implemented to resolve contamination by the simplest possible means:

•Overfilling with clean imported material
•Excavation and removal of contaminated soil and replacement with clean imported fill where the original ground level has to be maintained
•The covering of sloping surfaces when the contaminated inner cores of raised mounds are exposed or deep cuts are formed for canal construction through raised areas
•Special arrangements for prevention of direct contact and erosion when excavations are lakes bring subsurface contamination into conflict with open water
•Change of land use

Filling of large areas of land poses many difficulties in locating supplies of suitable material and transporting it to the site. If, for instance, a site of 16 ha is filled to a depth of 1 m, the import of 160,000 m of material involves possibly 20,000 vehicle movements between site and source of fill. This traffic is clearly undesirable in an urban area.

Ideally, the material to best deal with heavy metals and, indeed, many other contaminants, would be clay; this is not always satisfactory as a working base for construction and could lead to problems later due to its inherant instability in changing weather conditions.

Estuarine sand containing approximately 10% silt or pit dug sand with the same silt content could provide the desired protection to deal with metals, but experience with such material has not been satisfactory. Dredging for estuarine sand of the correct constituency may not be permitted at the time it is needed for development, and in any event, the unloading of vessels by conventional means which would be essential to preserve the silt content, would be inordinately expensive.

Put dug sand providing a minimum silt content of 10% is obtainable, but a consistent upper limit of silt in local sources is virtually impossible to achieve. Such material has been used already at Thamesmead and found wanting because excessive silt in the sand causes the site to become a quagmire during bad weather.

Hydraulic Fill Using Sea Sand

A large part of the Western area of Thamesmead has been filled with hydraulically placed sea dredged sand for construction purposes. The sand is taken from the North Sea by dredger and pumped ashore using river water as a transport medium in the proportion of approximately 10 to 1 by volume. Water is drained back to the river leaving the sand which is sharp and contains a lot of shell, but little or no silt.

This method, previously regarded as unsatisfactory for dealing with contaminated land due to the lack of fines, is being adopted for capping some areas by taking into account the additional thickness of surface soil necessary to create a suitable environment for plant growth. Extra top/sub-soil is necessary for shrub planting and large tree pits are essential, but the advantages of the fill method are considerable, particularly in respect of its lack of en-

vironmental impact on surrounding areas. Sites are self draining and the material provides a clean working platform for construction work. Topsoil is placed late in the construction period.

Other departments in the Greater London Council are dealing with major development schemes which are in no way associated with Thamesmead. Major road schemes fall into this category, and construction work often produces substantial quantities of surplus excavated material which must be transported some distance for disposal. By arrangement with the department concerned, it has been possible to obtain good quality material for reclamation work at no cost when such projects are close to Thamesmead.

Similar arrangements have been made between general contractors in the South East London area and a schedule contractor employed by the Thamesmead General Manager. In all cases, the source of material is inspected and, where necessary, a full historical check and sample analysis are made before acceptance. More than 200,000 m³ of material have been obtained by these means to date; these materials very often have been spread and levelled on-site without charge.

The Arsenal Gas Works

The grossly polluted condition of the old Arsenal gas works site prompted the Assessment Panel to recommend a change of land use whereby all building work within the area would be prohibited. The ground has been saturated by liquid residues during three generations of gas production going back to approximately 1850. These liquid, accompanied by high levels of other contaminants, have produced a below ground environment of considerable risk to construction workers.

It is fortunate that a nearby site intended for open space could be relocated, leaving a more suitable area available to make up the loss of building land. The gas works site has now been covered with at least 1.0 m of broken concrete and rubble from demolition works, followed by a layer of coarse shingle and then capped with a 0.3 m layer of clay graded to falls and taken down at least 1.0 m below ground at the perimeter. Open space and playing fields will be established on the site, but trees will only be planted outside the capping. The depth of subsoil/topsoil on the clay will be not less than 0.5 m and will exceed 1.0 m in part.

The opportunity for this kind of land exchange is rare and can only be exploited in a situation where area planning and project management activities are undertaken comprehensively.

Corrosion Problems and Deterioration of Concrete

As a matter of course, all sites are subject to investigation to establish their geophysical properties and natural levels of acid sulphates. On some sites at Thamesmead, excessive levels of acid sulphates have demanded special protection to piles, especially where other concrete damaging materials are in close association. In such cases, pile shells have been coated with 2-3 applications of an epoxy resin-based coating.

In most situations where pile protection of this kind has been necessary, it has arisen because of deposits of industrial waste used to reclaim areas of marsh. Interestingly, very high levels of acid sulphate (e.g., pH 3.5, Sulphase 5.4%) have been located on sites entirely free of industrial pollution. Similar results have been obtained at depths of 2.0 m or more and presumably arise from natural decomposition of peat by microbial activity or (most likely) the ingress of saline water from the Thames estuary in earlier times.

DISPOSAL OF CONTAMINATED MATERIAL

The requirements of the Control of Pollution Act 1974 would have placed the development of a large part of Thamesmead in jeopardy had it not been possible to provide on-site disposal facilities for contaminated material from construction sites. Construction of a new river wall as part of the London flood defense scheme created a space between it and the old river wall of approximately 350,000 m³. This space was licensed as a disposal facility suitable to receive contaminated material excavated at Thamesmead. The facility, which was the first one of its kind in London, has proved

to be a major success in the rehabilitation of contaminated land while providing an additional bonus in the reclamation of an area of river bed without the need for importing material. The reclaimed land, now suitably capped with clean material, will be used for housing development.

A similar space has been created with the construction of an adjoining section of river wall, and a license has been granted for the use of this for disposal of contaminated material. In both cases, the disposal license allows the burial of bagged fibrous asbestos from the cleanup operations described above. Together, the two sites will provide more than 12 ha of riverside development land.

RECLAMATION AND RECYCLING

Like many sites in the older run down industrial areas of London and other cities, the land at Thamesmead is not only contaminated with the waste products of manufacture but also contains the remains of generations of substantial buildings. Reclamation and redevelopment normally demand the import of clean fill and export of excavated spoil and building rubble. It is unusual to draw major development advantage from such operations. Because of the size and form of the Thamesmead project, however, it has been possible to adopt a broad environmental policy whereby all excavated spoil is retained and concrete rubble converted for reuse.

Controlled use of contaminated material to create new development land in conjunction with flood defense works is of considerable financial advantage to Council and developers alike. A similar advantage has been derived from removal and crushing of old concrete structures to provide substantial quantities of foundation material for roads and hardcore for general construction purposes virtually at the point of use. Combined with the ability to accept unwanted material from other developments for capping in contaminated areas, a comprehensive approach to reclamation and recycling has proved technically and financially successful.

THE FUTURE

Much of the old Arsenal land still needs to be examined; part of this is the estimated 1,000,000 m³ elevated area of Tripcock Point. This mound is covered in dense thicket and is composed almost entirely of ash, industrial residues and gas works waste. It was shaped to enclose a network of narrow roads and railways between steep embankments into which explosives magazines and test facilities, etc., all contained in massive masonry enclosures, were built. This area presents a special challenge because as much of the present physical form of the site as possible should be maintained to enhance its intended use as a District Park and a wildlife study area.

Altogether, some 80 ha of Thamesmead still require investigation, most of which will demand an approach to reclamation which takes into account unusual physical difficulties. In one instance, an elevated although flat site of approximately 23 ha is really a former industrial waste site where waste was dumped on the remains of more than 100 buildings demolished by explosives. It will not be economical to recycle the concrete and masonry due to its depth below the surface, thus preventing the use of conventional driven piles for construction purposes. In this case, remedial measures to deal with pollution will have to be designed to meet additional requirements for stabilizing the site.

In another instance, the surface level of a site of approximately 35 ha will have to be elevated considerably for drainage purposes using hydraulic filling methods. Care will have to be taken to find a suitable means of keeping water, which is pumped ashore as the vehicle for fill displacement, out of contact with elevated berms of contaminated waste which are immediately adjacent.

It is hoped the investigation of the outstanding areas of land at Thamesmead will be completed by the autumn of 1985, by which time it will be possible to reflect on the lessons learned over the preceding 10 yr. So far, it can be said that the Thamesmead site is most noteworthy for the variety of forms of pollution and the scale of the operation, rather than the intensity of contamination. It is anticipated that this will continue.

REMEDIAL ACTION FOR GROUNDWATER PROTECTION CASE STUDIES WITHIN THE FEDERAL REPUBLIC OF GERMANY

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INTRODUCTION

Remedial actions at abandoned landfills and contaminated industrial sites are a growing challenge for water and waste authorities and for scientists in the Federal Republic of Germany. Of primary concern are harmful impacts on public health, agriculture and groundwater.

Past and current waste disposal practices and careless handling and storage of hazardous materials have resulted in contaminated soils, surface water and groundwater. While remedial actions are often designed to neutralize the hazards of contamination in situ, without touching or excavating the contaminated materials, field experience demonstrates that remedial actions are still more difficult than safe handling and disposal of hazardous wastes in the first place.

IN SITU TREATMENT OF
ARSENIC CONTAMINATED GROUNDWATER Oxidation

One of the earliest in situ German groundwater remediation projects was carried out in Nievenheim, Land Nordrhein-Westfalen, near Cologne, between 1971 and 1979. From 1913 to 1971, about 4,200 metric tons of calcium arsenate-containing sludges had been disposed of on the site. These sludges were the by-product of a sulphurous acid flue gas washing process in a nearby zinc ore smelter. Arsenic trioxide (As_2O_1) in the effluent had precipitated with calcium hydroxide ($Ca(OH)_2$) at pH 8 as calcium orthoarsenate ($CA_3(AsO_4)_2$).

The groundwater had maximum concentrations of arsenic at 56 mg/l, compared to a normal level of 0.01 mg/l. Sediment analysis revealed 10 to 170 mg As/kg, with an average of 78 mg/kg. The contaminated plume covered an area of about 180,000 m^2, and about 820,000 m^3 of groundwater was estimated to be contaminated. In the contaminated aquifer, anaerobic reducing conditions were prevalent with high iron concentrations (140 mg Fe^{2+}/l), negative Eh and low pH-values (3.1-7). No arsenic was found in the River Rhein, only 300 miles north of the sludge disposal site.

Four possible remedial action alternatives were discussed:
- Excavation and treatment of polluted soil
- Extraction and treatment of contaminated groundwater
- Encapsulation of the heavily contaminated area
- In situ oxidation of arsenic compounds

The fourth alternative was chosen. Four years of groundwater monitoring indicated that the plume was shrinking and the Eh and pH-values increasing (Fig. 1). It therefore appeared possible to oxidize the trivalent arsenic into pentavalent arsenic and cause precipitation of complex arsenic-iron-manganese compounds.

Laboratory tests with bleach (NaOCl), hydrogen peroxide (H_2O_2) and potassium permanganate ($KMnO_4$) led to the decision to use a solution of 2 g $KMnO_4$/l for injection into the ground. 29,000 kg of KMnO (0.472 g/m^3 of water saturated sediment) were injected into 17 wells and piezometer wells. Arsenic concentrations were reduced in average from 13.6 mg/l in 1975 to 0.06 mg/1 in 1977. However, an increase to 0.4 mg/l in 1979 indicated that the mixing of contaminated water and oxidizing solution was not sufficient.

Total costs for disposal of arsenic containing sludges, monitoring and injection of $KMnO_4$ amounted to DM 750,000.[1,2,8] [Ed. note: 1 DM = $0.34 US]

TETRACHLOROETHYLENE REMOVAL Soil flushing
FROM GROUNDWATER

In 1979, a storage tank in Sindelfingen, Land Baden-Wuerttemberg was overfilled with tetrachloroethylene, spilling and contaminating the soil and groundwater. The contaminated soil was immediately excavated and disposed of as a hazardous waste. A mixture of dissolved and liquid chlorinated hydrocarbons was then pumped from the bottom of the excavated pit, and the polluted groundwater was treated in a mobile activated carbon filter unit and discharged into a sewer. Investigation into the migration of the hydrocarbons revealed high concentrations of tetrachloroethylene in the aquifer. An estimated 14 metric tons of hydrocarbons had been discharged into the aquifer and had moved upstream.

1971 ——   ▨ CONTAMINATED SITE
1975 — —
ISO - CONCENTRATION LINES
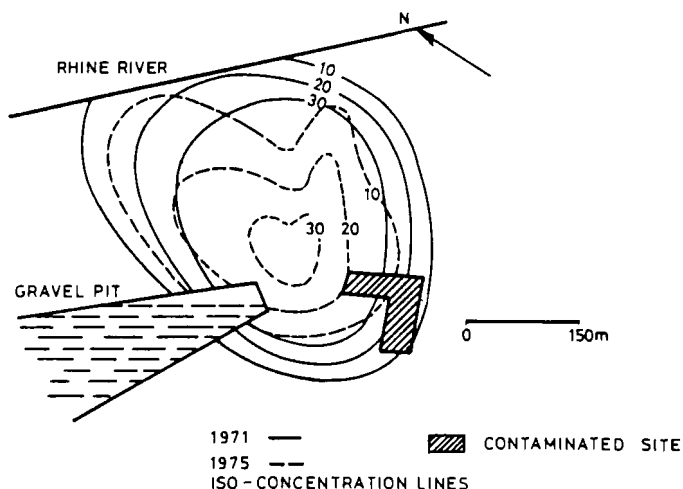
Figure 1
Shrinking of the Plume of Arsenic in Groundwater

An attempt was made to leach the chlorinated hydrocarbons in the 2,500 m² spill area. Water was infiltrated into the ground in 90 m long ditches at the rate of 2 m³/hr. Within 18 months, pollution had decreased by 50%. The leaching liquid and polluted groundwater were pumped out of eight wells and treated in an activated carbon filter. The treated water was used for further leaching, and within 18 months, 17 metric tons of hydrocarbons were recovered.[1,2,3]

IN SITU TREATMENT OF GROUNDWATER CONTAMINATED WITH HYDROCARBONS

Groundwater contamination with aromatic and aliphatic hydrocarbons was discovered on an industrial site near Frankenthal, Land Rheinland Pfalz. This contamination was caused primarily by fuel oil along with benzene, xylene, toluene, napthalene and styrene seeping into the ground. While liquid fuel oil was pumped out, remaining hydrocarbons saturating the soil were estimated at 20 to 30 metric tons. Aromatic hydrocarbons were found downstream of the site in the direction of a municipal water works. The plume migration had stopped, however, due to pumping of the shallow aquifer.

The upper Rhine Valley aquifer is sedimentary, mainly from the quaternary period. It has an irregularly layered structure with sand and gravel layers of variable thickness and horizontal extension separated by clay and loam lenses or aquitards. In the area of the contaminated site, a distinct high permeable layer of approximately 16 km thickness ($K_f = 5.10^{-4}$ m/sec) overlies a clay barrier of a thickness of 48 km or more. The aquifer has a microstructure ranging from fine sand to coarse gravelly sand.

After three years of pumping, the water table in the aquifer had been lowered to a 1 m depth above the impermeable layer. Groundwater flow was extremely low.

Combined hydraulic flushing and induced biodegradation of the hydrocarbons was favored over containment of the contaminated aquifer by using impermeable walls.[7] It was decided to take a two-step remedial action:
• Hydraulic measures to control the flow of groundwater
• Biological and chemical treatment of contaminated groundwater in situ and in an on-site treatment plant

The responsible water authority required that nutrients injected into the aquifer to accelerate biodegradation and the flushed contaminants be kept within a defined area so that the surrounding aquifer was not contaminated.

The effects of the hydraulic measures were simulated on a numerical groundwater flow model. The model was calibrated at the first stage of the action when the aquifer had a level of 1 to 6 m of clean groundwater (drinking water standard) at a steady state flow with all polluted parts of the aquifer "under water".

Two separate recirculation lines were installed, one for the flushing water (5 l/sec) and the second for clean injection water (20 to 30 l/sec). The latter was operated throughout the remedial action to control spreading of contaminants from the treated area. The recirculated flushing water, contaminated with hydrocarbons and biodegradation by-products, was stripped and filtered before re-infiltration (Fig. 2). Biodegradation was enhanced by controlling the dosage of the nutrient nitrate and by increasing the water temperature 10 °C. Laboratory experiments revealed that microbes present in the soil (5,000 microbes/g of soil) would degrade gasoline and benzene. Biodegradation of aromatic hydrocarbons was simpler than degradation of aliphatic hydrocarbons, and benzene biodegradation was better than that of xylene and toluene (Fig. 3). Microbial activity was controlled in the field by measuring nitrate concentration in the recirculated water. The maximum concentration was 500 mg/l, with an average of 300 to 400 mg/l.

The effectiveness of the remedial measures was monitored using samples from randomly located monitoring wells over 4 months. Significant differences in hydrocarbons concentrations were found. After three months it was found that aromatics had been degraded in the whole area, and aliphatics were reduced to about one-third of their initial concentration.[5,6,7,1]
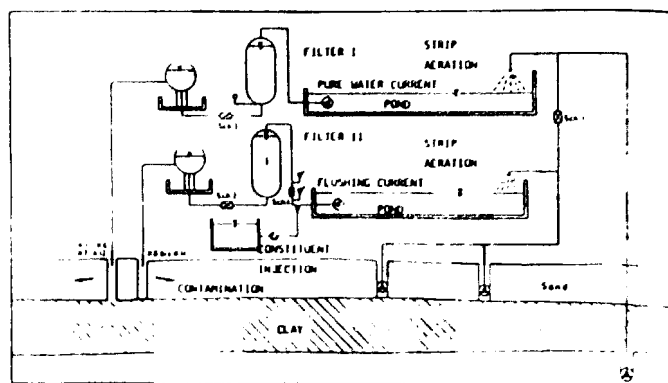
Figure 2
Groundwater Treatment Scheme
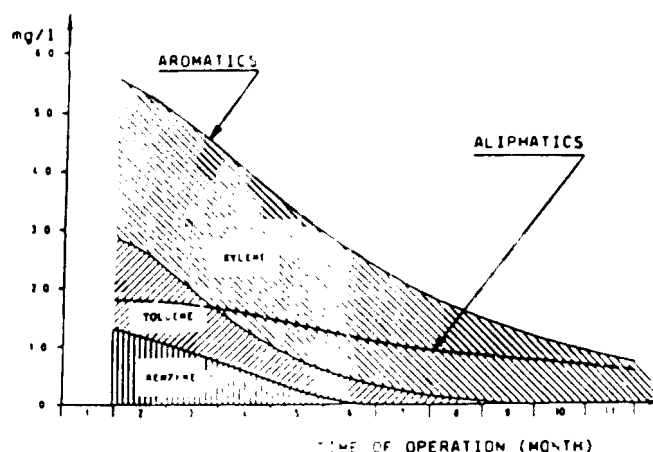
Figure 3
Biodegradation of Hydrocarbons

ENCAPSULATION OF HEXACHLOROCYCLOHEXANE ON AN INDUSTRIAL SITE

In January, 1979, it was discovered that hexachlorocyclohexane (HCH) had been disposed of on an industrial site in Gendorf, near Munich, Land Bayern. Residues from the production of the pesticide LINDANE were the source of this waste. The residues were a mixture of various isomers of HCH and some other "impurities."

The HCH waste had been disposed of on a concrete slab of an old building foundation and was covered with only 0.5 m of soil at the time of initial investigation. Detailed investigations by the Bavarian EPA revealed an HCH-waste layer of 2.0 to 2.5 m thick, covering an area about 250 m², 20 m above the groundwater table. The waste contained part dry powder and part pasty sludge. Contamination in the vicinity of the disposal site was very low: HCH levels in milk were 1/10 to 1/100, and in water 1/1000 of the maximum acceptable level.

Four alternatives for remedial action were considered:
• Removal and off-site disposal in a hazardous waste landfill
• Removal and disposal in the Herfa-Neurode salt mine
• Removal and incineration
• Encapsulation

The three removal alternatives were dismissed because of the enormous operational safety and emergency procedures which would be necessary for an excavation. In addition, the potential by-products of incineration of the HCH waste included 0.7 metric tons of chloride per metric ton of waste as well as dioxin or phosgene. Taking "no action" would also be unsatisfactory, as infiltrating

rainwater could cause HCH to leach into the groundwater, and HCH could also volatilize and escape into the atmosphere.

The site was therefore encapsulted to prevent these potential discharges from occurring. The vertical barrier, made of steel sheet piles (LARSEN profile No. 20), goes down to a depth of 3 m and is 426 m in length. The site is covered with an impermeable cap made up of 20 cm compacted gravel, 5 cm compacted sand, a 3 mm polyvinylethylene protective layer and a 1.5 mm PVC membrane. This cap overlaps the vertical barrier and is buried to a depth of 60 cm. A 60 cm layer of sand protects the PVC membrane and is covered by 20 cm of gravel, 8 cm asphalt and 3 cm asphalt concrete. The final cover has a 3% slope.

The site will receive long-term monitoring at three wells and has been designated in the register of land property to prevent any damage to the encapsulation in the future. The total cost for encapsulation and monitoring was DM 250,000.

DIOXIN-CONTAINING WASTE IN A HAZARDOUS WASTE LANDFILL

It was learned in 1983 that between 1969 and 1972, approximately 370 metric tons of dioxin containing waste (200 drums) had been disposed of in the Gerolsheim hazardous waste landfill. This dioxin waste was the result of the manufacturing of 2, 4, 5-T. Since 1972, the barrels containing dioxin had been covered possibly by acid tar wastes and by 20 m of unknown hazardous waste.

Adjacent to Gerolsheim lies Hessheim, a solid waste dump site. Both sites, still in operation, are located in former sand pits, and neither has a liner or leachate collection system. The Gerolsheim site is about 15 hectares and the Hersheim, 17 hectares. Gerolsheim has received approximately 3.2 million metric tons of waste, about 20% of which is solid waste.

The information about the dioxin wastes was released by the generator, the Christopher Boehringer Company, at a time when there was high interest in the burial location of dioxin wastes in Europe, particularly the 41 Seveso drums.

The responsible authorities initiated immediate investigations to determine if there were any dioxin emissions. Dioxin was not found in groundwater, nor in the soil, nor in plants or animals. The next steps were to: (1) pinpoint the specific location of the dioxin waste in the landfill; (2) evaluate the likelihood of its migration; (3) conduct a risk assessment; and (4) propose options for remedial action.

Results of geological investigations are shown in Figure 4. The second aquifer was found to be contaminated, leading to the assumption that the quaternary sediments ($K_f 10^{-7}$ to 10^{-8} m/sec) contained "windows." The third aquifer was uncontaminated. Leachates from the landfill site which were polluting the groundwater were primarily inorganic salts. Volatile chlorinated hydrocarbon contamination downstream from the site was significantly higher than upstream (up to 729 μg/l). Analysis of downstream sediments showed hydrocarbon contamination to a depth of 36 m. These sediments contained 100 mg volatile and non-volatile hydrocarbons/kg along with phenols and other coupling substances. Neither dioxin nor heavy metals were found in these extensive investigations.
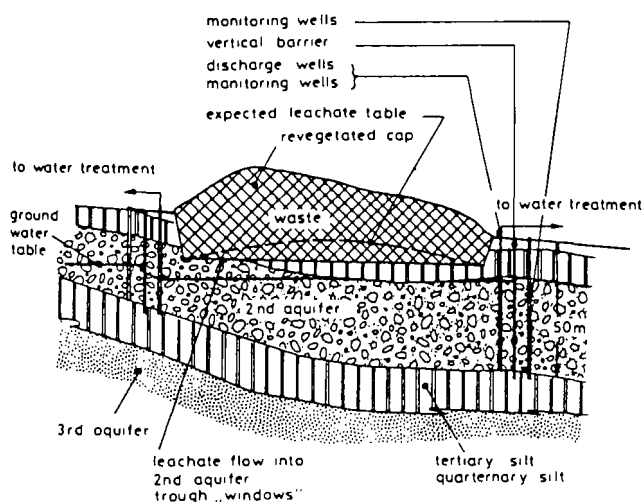
Gases being emitted from the site include methane, hydrogen sulfide, halogenated hydrocarbons and aromatic compounds.

The emotions of citizen groups from the villages of Gerolsheim and Hessheim have influenced discussions on remedial action. The citizens have demanded removal of all of the wastes, but in particular the dioxin waste. Authorities consider this impossible and unnecessary because of the dangers of excavation, the lack of available disposal facilities for dioxin wastes and because of the relative lack of groundwater contamination. Encapsulation appears to be the appropriate remedial response as it will protect against potential impacts of the waste, including groundwater contamination and air pollution. Encapsulation proposals include construction of vertical barriers extending below the second aquifer (30 to 50 m), and placement of a nearly impermeable (not greater than 10^{-9} m/sec) cap. The expected leachate 3.8m³/sec) will either be treated in an industrial sewage treatment plant or in a separate onsite treatment facility.

The groundwater will be tested for pH, electrical conductivity, dissolved solids, chlorides, sulphur peroxide, chemical oxygen demand, total organic carbon, volatile halogenated hydrocarbons, total cyanides, free cyanides, phenol index, phenol index after distillation, heavy metals (mercury, cadmium, lead, chromium, nickel, copper and zine) and toxicity (Beckmann rapid analysis Microtox). If the phenol index after distillation is greater than 100 μg/l, groundwater will be analyzed with gas chromatography and mass spectrocopy for 2, 4, 5-trichlorophenol. If the result is greater than 100 μg/l, a 2, 3, 7, 8-TCDD analysis will be necessary.

CONCLUSIONS

While only a few case studies have been illustrated, they represent trends of remedial activities in the Federal Republic of Germany. Hydraulic measures combined with groundwater treatment are used extensively to cope with contamination by halogenated hydrocarbons,[3] and enhancement of microbial degradation in aquifers is a promising approach for the future.

Although small hazardous waste dump sites were excavated and the waste disposed of according to present standards in hazardous waste disposal facilities, encapsulation is presented as the only appropriate remedial alternative, particularly for larger dump sites. This is particularly true where dioxin-containing wastes are suspected, because of the environmental risks connected with excavation and the problems surrounding its disposal in licensed disposal facilities. While encapsulation, using vertical barriers, slurry walls and clay caps or membranes may allow time to explore more permanent and effective solutions, it is likely that perpetual maintenance and reconstruction of the "container" will occur instead.

In situ treatment of contaminants in soil or groundwater is not possible if there are heterogeneously distributed mixtures of contaminants. Only in very rare cases, as with the arsenic treatment described, does it offer cost-effective solutions.

From these remedial actions at abandoned hazardous waste sites and contaminated industrial sites, it becomes obvious that careful handling and storage of hazardous substances and treatment of hazardous wastes in appropriate facilities to render it harmless before landfilling, will ultimately be much more cost-effective than the best available remedial action.

Figure 4
Remedial Action Proposal for the Hazardous Waste
Landfill Site Gerolsheim

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REVIEW OF THE DEVELOPMENT OF REMEDIAL ACTION TECHNIQUES FOR SOIL CONTAMINATION IN THE NETHERLANDS

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INTRODUCTION

With the discovery in 1978 of severe soil contamination under a new housing development in Lekkerkerk, the problem of soil contamination was introduced to The Netherlands. Since that time, an unflagging flood of contaminated sites has been discovered.

At present, it is estimated that the number of contaminated sites exceeds the 4000 uncovered during a 1980 inventory. About 1000 of these sites contain such severe contamination that some kind of remedial action will be required.

The large number of sites has demanded a stepped-up remedial action program which probably will not be finished before 1998. A further increase of the number of contaminated sites might push this date further forward.

The remedial action activities in Lekkerkerk consisted of the excavation of 100,000 m³ of contaminated soil and treatment of the contaminated groundwater. The soil was transported to a domestic refuse incinerator. There it was stored and gradually incinerated along with domestic waste. The total cost of the remedial action program in Lekkerkerk amounted to about $65,000,000 (US).

With a total yearly amount available for remedial action of about $60,000,000 (US) for the next three years, it is evident that remedial action like Lekkerkerk is out of the question. Thus the development of a more cost-effective remedial action technology is necessary. In this paper, the author gives an overview of the potential application of remedial action techniques developed and being developed in The Netherlands.

THE DUTCH SITUATION AND POLICY

The Dutch situation involving contaminated sites has some unique characteristics. First, the population density is high and therefore there is a great need for land. A policy which accepts a considerable amount of permanently contaminated land unsuited for certain types of human use is, in general, not acceptable. Second, in many parts of the Netherlands, particularly in the industrial areas where most of the contaminated land is situated, the groundwater level is high. Consequently, the contaminated soil is partially located in the saturated groundwater zone resulting in a serious danger of further propagation of the contamination via groundwater flow. Since mud groundwater is a source of drinking water, this situation is highly undesirable.

Finally, the character of the soil requires considerable effort in preparing a site for building. In the past decades, there has been extensive development of housing. For site preparation, demolition rubbish was often used as a cheap fill material. It seems that often, wittingly or unwittingly, great amounts of hazardous wastes were included with the harmless rubbish. This resulted in a number of new housing developments being constructed on seriously contaminated soil. Lekkerkerk is the most well known but certainly not the most severe example of these sites.

Because of this and similar situations, a considerable number of cases required quick remedial action. Since the required technology was not yet available, this cleanup program resulted in the construction of temporary storage facilities, in which contaminated soil is stored while awaiting ultimate disposal.

The situation in The Netherlands resulted in a soil contamination policy based on the principle that the remedial action program must remove the contaminants from the soil. Containment is only acceptable when the removal would result in disproportionate cost or would cause an unacceptable risk to public health. Moreover, the excavation and transportation of contaminated soil abroad is unwanted. Project proposals containing such solutions are not funded under the framework of the Soil Clean Up (Interim) Act.

Because of this policy, this paper only deals with the technology concerned with in situ soil treatment and soil treatment after excavation.

CLASSIFICATION OF REMEDIAL ACTION TECHNIQUES

This paper described technology which is now operational in the Netherlands or which is presently being developed and is expected to become operational within a reasonable time. A more detailed description of the Dutch situation is given in Reference 1. A more comprehensive review which also contains more theoretical techniques is given in References 2 and 3. The remedial action techniques can be subdivided into three main categories (Fig. 1):
• Thermal treatment
• Treatment by extraction
• Biological treatment

Thermal Treatment

The contamination is removed by heating the contaminated soil. First, the soil is excavated. Then thermal treatment is performed in an installation with direct (convection or radiation) or indirect (conduction) heat transfer.

When the temperature in the installation is relatively low, incomplete incineration of the contaminants occurs. Post-treatment of the gas must then be effected. The required destruction can be achieved by incineration at high temperatures in an afterburner, thermal treatment at moderate temperatures using appropriate catlysts or treatment at low temperatures followed by scrubbing of the gas and purification of the scrubbing liquid.

Treatment after excavation

	steam stripping
	evaporation by thermal treatment (T = ± 300 °C)
Thermal treatment	evaporation by thermal treatment (T = ± 700 ° C)
	incineration (T > 800 ° C)
	aqueous solution
Extraction	organic solvent
	flotation
	landfarming
Microbiological treatment	composting
	(industrial system)

In situ treatment

Thermal treatment	steam stripping
Extraction	aqueous solution
	landfarming
Microbiological treatment	bioextraction

Figure 1
Summary of Remedial Action Techniques

In the case of in situ treatment, steam is injected into the soil. The contaminants diffuse into the gas phase and then are transferred to the surface where, if necessary, adequate post-treatment takes place.

Extraction

The extraction process consists basically of mixing the contaminated soil with an extracting agent to transfer the contaminants from the soil particles to the extracting agent. With this process, it is possible to remove not only contaminants that are soluble in the extracting agent (in general an aqueous solution, but sometimes an organic solvent), but also contaminants that are in fact insoluble in the extracting agent. In the latter case, it is required that the extracting agent have properties favorable to the formation of stable colloidal suspensions of the contaminants.

After extraction, the purified soil particles are separated from the extracting agent containing the contaminants. The extracting fluid is subsequently purified.

Microbiological Treatment

Microbiological treatment implies the removal of contaminants by biodegradation. After excavation of the soil, this treatment can be accomplished by landfarming, composting or treatment in a designed installation. The last possibility is still more or less theoretical since it is dubious that a sufficiently high biogradation velocity can be reached to result in a sufficiently low residence time.

In situ microbiological treatment can take place by landfarming and bioextraction. The former technique is only applicable when the contaminants are concentrated in a top soil layer having a maximum depth of about 0.5 m.

POTENTIAL APPLICATION OF REMEDIAL ACTION TECHNIQUES

The potential for successful application of the various remedial action techniques depends on the type of contaminants, the type of soil and the location of the contaminants with regard to the ground level. These three aspects are discussed below.

Type of Contaminant

Contaminants can be subdivided into organic and inorganic. The inorganic category can be surther subdivided into heavy metals and metalloids on one hand and cyanides and cyanide complexes on the other hand. Finally, a miscellaneous category of inorganic contaminants consisting of acids, phosphates and ammonia remains.

The organic contaminants are subdivided into aliphatic and aromatic hydrocarbons, polynuclear hydrocarbons, halogenated hydrocarbons and pesticides. These subdivisions finally result in seven main categories of contaminants:
•Aliphatic and aromatic hydrocarbons
•Polynuclear hydrocarbons
•Halogenated hydrocarbons
•Pesticides
•Heavy metals and metalloids
•Cyanides and cyanide complexes
•Miscellaneous (acids, phosphates, ammonia, etc.)

Type of Soil

In Reference 1, a subdivision of types of soil into five categories was made:
•Sandy soils
•Loamy soils
•Clay
•Peat
•Stratified soils

For each of these soils, the application of each of the remedial action techniques can be determined. However, the present state-of-the-art of the remedial action techniques makes such a detailed differentiation by type of soil premature.

Therefore, in practice, a differentiation between only two types of soil is made. There are the sandy and loamy soils which can be cleansed relatively easily, and there are the clay, peat and stratified soils where the application of remedial action techniques is limited. In this paper, the latter differentiation is used.

Location of Contaminants

The location of the contaminants with regard to the ground level is important for two reasons: (1) the potential for excavation of contaminated soils is practically limited and (2) certain in situ remedial action techniques can be applied only when the contaminants are located near the ground level (landfarming and steam stripping).

Remedial Action Evaluation

The evaluation of techniques based on type of contaminants and type of soils has been accomplished, and the results are given in Tables 1 through 4. Tables 1 and 2 deal with remedial action techniques after excavation, while Tables 3 and 4 deal with in situ treatment. The tables are mainly based on information derived from Reference 1.

The symbols used in the tables are:
+   applicable
+ / – applicable in some cases
– / + in general, not applicable
–   not applicable

It must be emphasized that these tables describe potential applications of techniques, not actual ones.

Given a specific contaminant and a type of soil, one can determine which technique or techniques can be applied by using Tables 1 through 4. In case more than one technique is applicable, a choice must be made.

At present, the actual availability of a technique often determines the final choice. However, in the near future, when the total number of remedial possibilities will certainly increase, criteria other than availability will become important. In Tables 5 and 6,

		Thermal treatment				Treatment by extraction			Micro-biological treatment	
		steamstripping	evaporation (T=±300°C)	evaporation (T=±700°C)	incineration (T=±800°C)	aqueous solution	organic solvent	flocation	landfarming	composting
aliphatic and aromatic hydrocarbons	low boiling point	+	+	+	+	+/-	+/-	+/-	+	+
	high boiling point		+/-	+	+	+/-	+/-	+/-	+	+
polynuclear hydrocarbons			+/-	+	+	+/-	+/-	+/-	+/-	+/-
halogenated hydrocarbons		+/-	+/-	+	+	+/-	+/-	+/-	+/-	+/-
pesticides			-	+/-	+	+/-	+/-	+/-	+/-	+/-
heavy metals and metalloids		-		-		+/-		+/-		
cyanides	free cyanide	-		+	+	+/-		+/-	+	+
	cyanide complexes	-		+	+	+/-		+/-		
miscallenneous		-		-		+/-		+/-	-/+	-/+

		Thermal treatment				Treatment by extraction			Micro-biological treatment	
		steamstripping	evaporation (T=±300°C)	evaporation (T=±700°C)	incineration (T=±800°C)	aqueous solution	organic solvent	flocation	landfarming	composting
aliphatic and aromatic hydrocarbons	low boiling point	+/-	+	+	+		-/+	-	+/-	+/-
	high boiling point		+/-	+	+	-	-/+	-	+/-	+/-
polynuclear hydrocarbons			+/-	+	+	-	-/+	-	+/-	+/-
halogenated hydrocarbons		-	+/-	+	+	-	-/+	-	-/+	-/+
pesticides		-	-	+/-	+		-/+	-		
heavy metals and metalloids		-	-			+/-	-/+	-/+		
cyanides	free cyanide	-	-	+	+			-	+	+
	cyanide complexes		-	+	+	-				
miscallenneous				-		-/+			-/+	-/+

some of these criteria are given for techniques to be used after excavation and for in situ techniques. The symbols used in these tables are as follows:

+   favorable or not problematic
0   limiting or slightly negative
−   strongly limiting or negative

The following paragraphs contain explanatory notes on many of the criteria.

•Energy demand is extremely important for the thermal techniques. With increasing temperatures in the process unit, energy costs increase; hence, increasing temperature is a negative feature.

•Treatment by extraction and/or microbiological treatment often requires the addition of other chemicals such as nutrients and/or oxygen. Techniques are judged favorable if these additions can be avoided.

The amount of residue from thermal techniques, if they are provided with adequate post-treatment of the gases, is negligible. The extraction techniques are judged negative on this feature, especially when the percentage of fine particles in the soil increases.

When more than one contaminant is present, the limited number of contaminants which can be removed by steam stripping is limited. Hence, the technique is generally judged to be negative. The application of the remaining thermal techniques is limited when the contaminated soil contains heavy metals and/or metalloids. Treatment by extraction is very attractive in this case.

Microbiological techniques normally degrade only a single chemical. Thus, when numerous contaminants are present simultaneously, microbiological techniques are not highly rated.

A reliable estimate of the cost is difficult to make at present; most of the techniques are still in development and only a few have been used in the field. As a result, only a range within which the real costs are expected to vary is given in Table 5. The amounts reported include only the actual remedial action cost excluding the

cost for excavation, transport and possible cost for dumping the cleaned soil afterward. The costs are strongly determined by the type of soil.

As discussed before, sandy and loamy soils are relatively easy to cleanse. Therefore, the lower amount in the range given in Table 5 in general will be valid for these types of soils. Conversely, the cost of cleaning up clay, peat and stratified soils will be near the upper limit of the given range.

Any required increase in temperature in the thermal techniques will result in an increase in cost. Comparing thermal and extraction techniques shows that steam stripping and evaporation at lower temperatures (± 300° C) are cheaper than extraction. Evaporation at higher temperatures (± 700° C) and incineration are more expensive than extraction. The cost of microbiological degradation is promising on comparison with the other techniques. However, results of full scale application of this technique is not currently available. This makes any definitive conclusion about cost advantages premature. Since the cost of in situ treatment strongly depends on the total treatment time, no reliable estimate of these costs can be given.

In Tables 1 through 6, the potential combinations of different techniques together with some features are given.

During the last four years, much research has been performed in order to develop full-scale remedial action techniques. In the next few paragraphy, the current state-of-the-art of both the treatment after excavation and in situ treatment is given. The review is limited to those techniques which are developed at least to pilot-plant scale.

However, various contractors have designed treatment installations which could result in either pilot-plant or full-scale installations at any time. Due to uncertainty about the time required to execute these designs, no attention is given to them.

Most of the techniques to be described have been developed with financial support from the Dutch government. A more extensive review of the actual situation is given in Reference 4.

Table 3
Potential Applicability of In Situ Remedial Action Techniques; Sandy and Loamy Soils

		thermal treatment	treatment by extraction	microbiological treatment	
		steamstripping	aqueous solution	land farming	bioextraction
aliphatic and aromatic hydrocarbons	low boiling point	+/-	-/+	+	+/-
	high boiling point	-		+/-	+/-
polynuclear hydrocarbons		-		+/-	+/-
halogenated hydrocarbons		-	+/-	-/+	-/+
pesticides		-	+/-	-	-
heavy metals and metalloids			+/-		-
cyanides	free cyanide	-	+/-	+	+/-
	cyanide complexes	-	-/+	-	-
miscallenneous			+/-	-/+	-/+

Table 4
Potential Applicability of In Situ Remedial Action Techniques; Clay, Peat and Stratified Soils

		thermal treatment	treatment by extraction	microbiological treatment	
		steamstripping	aqueous solution	land farming	bioextraction
aliphatic and aromatic hydrocarbons	low boiling point	-	-/+	+/-	-/+
	high boiling point			+/-	
polynuclear hydrocarbons			-	+/-	
halogenated hydrocarbons			+/-	+/-	-
pesticides				+/-	
heavy metals and metalloids			+/-	-	
cyanides	free cyanide		+/-	+/-	-/+
	cyanide complexes	-	+/-	-	-
miscallenneous				-/+	

Table 5
Selection Criteria for Remedial Action Techniques After Excavation

	steamstripping	evaporation							
Energy demand	o/-	o/-	-		+	+	+	+	+
Other substances required	+	+	+	+	o	o	o	o	o
Amount of residu	o	+	+	+	-		-	+	+
Possibility of application when more contaminants are present simultaneously	-	o/-	o	o	+	+	+		
Cost (dutch guilders/m³)	125 to 250	125 to 250	160 to 500	250 to 650	80 to 320	160 to 320	80 to 320	40 to 160	40 to 160

Note: 1 Guilder = $0.31 US

Table 6
Selection Criteria for In Situ Remedial Action Techniques

	thermal treatment	treatment by extraction	microbiological treatment	
	steamstripping	aqueous solution	land farming	bioextraction
Energy demand		+	+	+
Other substances required	+	o	o	o
Amount of residu	o		+	o
Possibility of application when more contaminants are present simultaneously		o		-
Cost (dutch guilders/m³)	+	+	+	+

AVAILABLE TECHNIQUES FOR TREATMENT AFTER EXCAVATION

Thermal Treatment

Evaporation at ± 300° C

A full scale thermal treatment plant has been developed by Ecotechniek (Fig. 2). An extensive description of the installation is given in Reference 5. The contaminated soil is heated to 200-300° C, and the gases are burned at approximately 800° C with the addition of extra air. In order to minimize the total energy need, an ingenious heat recirculation system is used.

The total capacity of the installation strongly depends on the moisture content of the soil and the type of soil. For sandy soils (low moisture content), the capacity is about 30 m³/hr (48,000 m³/yr) while for clay (high moisture content) this capacity reduces to about 15 m³/hr (24,000 m³/yr). In the latter case, the total load of the installation still amounts 30 m³/hr, but the need to mix the feed with clean sandy soil to achieve the optimum mixture in the

installation reduces the soil cleaning capacity to 15 m³/hr. The reduction in capacity can be avoided by mixing with sandy soils contaminated with substances which can be removed by a thermal treatment system.

Up to now, several ten thousands of cubic meters of soil contaminated with various substances such as benzene, toluene, xylene, naphtalene, diesel oil and gasoline have been successfully treated using available incinerators.

Evaporation at ± 700° C

The "Afvalverwerking Rijnmond" (AVR) in Rotterdam has an installation for the incineration of domestic refuse. To a limited degree, contaminated soil can be treated in this installation by mixing it with the domestic refuse. Due to the grate construction, and the mixing thereon, only a 10% soil-90% refuse mixture is possible. This limits the capacity for contaminated soil to about 50,000 m³/hr. The temperature in the installation exceeds 500° C while the gases are heated up to at least 850° C. The cleaned soil is mixed with the slag from the domestic refuse, thus making reuse of the soil questionable. The contaminated soil from Lekkerkerk was cleaned (±100,000 m ÷) in this unit. Although this installation was not developed for the treatment of contaminated soil, its potential capacity requires mentioning it here.

The Nederlandse Beton Maatschappij (NBM) has developed a pilot-scale incinerator consisting of a rotary kiln in which the contaminated soil is headed by a heat exchanger depending on the type of contaminants, up to a maximum temperature of 850° C. (Fig. 3). The gases are incinerated in an afterburner at a temperature of about 1,200° C.

The capacity of the pilot-plant is 0.3 m³/hr. When the test program is completed, scaling up to a full-scale plant with a capacity of about 10 m³/hr (16,000 m³/yr) is foreseen. The total energy demand is reduced by using heat recovery.

The installation has been tested with clean soil. The results indicated that the design criteria with respect to the temperatures in the rotary kiln and the afterburner were achieved. At the time of the preparation of this paper, no results of the tests with soil contaminated with cyanides were available.

Incineration at a Temperature > 850° C

The AVR disposes of wastes in a hazardous wastes incinerator. The installation consists of a rotary kiln in which a temperature of about 1,300° C is maintained. It is estimated that an excess capacity of about 5,000 m³/yr is available. This can be used for the incineration of very severely contaminated soils (containing PCBs, pesticides). Since this installation is not specially designed for the incineration of contaminated soil, no further attention has been paid to it here.

Bob Kalis/Esmil is developing an incinerator consisting of a fluidized bed in which contaminated soil is incinerated at temperatures up to 850° C. At present, a pilot plant with a capacity of about 0.3 m³/hr is available. When test results are satisfactory, a full-scale installation is planned with a capacity of about 17,000 m³/yr. A process schematic of the installation is given in Figure 4.

Treatment by Extraction

Aqueous Solution

The Hollandsche Beton Groep NV (HBG) has developed, with the support of the Netherlands Organization for Applied Scientific Research (TNO), a full-scale extraction installation with a capacity of about 15 m³/hr (24,000 m³/yr). During the test program in a pilot-plant, soil contaminated with cyanides, both free and complexed, was cleaned successfully. Because of the flexible nature of the extraction process, it may be expected that final applications of this technique will be broader than simple cyanide removal. They may include, for example, heavy metals and metalloids and polynuclear hydrocarbons. The present installation is limited to the cleaning of sandy soils. Further research might result in an extension to soils with a higher percentage of fine particles (loamy soil). The process scheme is shown in Figure 5.
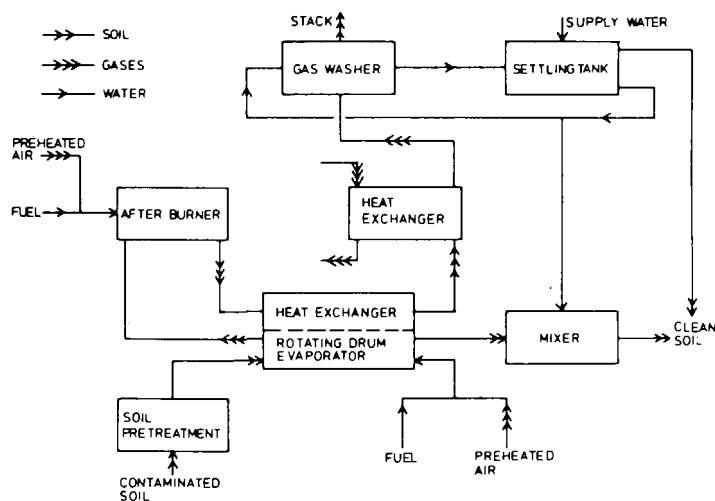
Figure 2
Treatment of Soil by Evaporation at 200-300° C and Destruction of Gases at About 800° C in an Afterburner
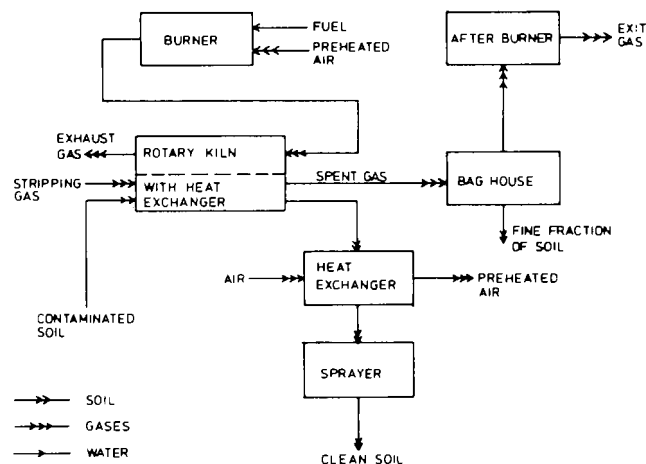
Figure 3
Thermal Treatment by Indirect Heat Transfer and Evaporation of Contaminants
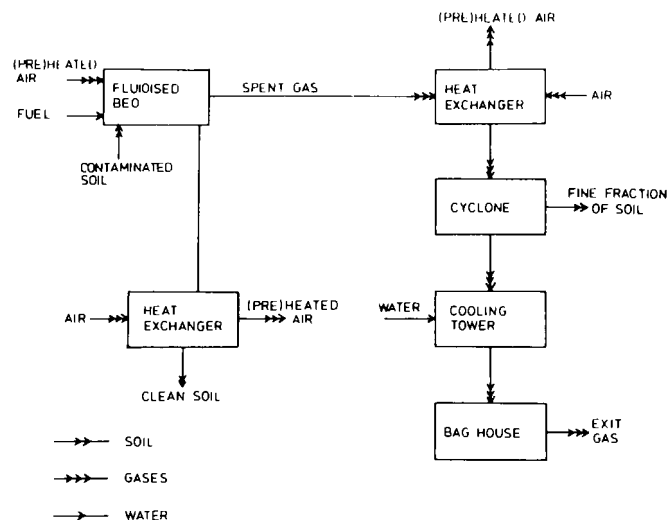
Figure 4
Thermal Treatment by Incineration in a Fluidized Bed

Ecotechniek BV has developed an installation based on washing contaminated soil with heated water. The capacity of the installation amounts to about 70 m³/hr (110,000 m³/yr). The primary application appears to be sandy soils contaminated with oil. Due to the heating of the soil, the contaminants are released from the sand particles. Recently, the installation was used for the cleaning of a sandy beach that was contaminated by oil from a shipping disaster.

Bodemsanering Nederland BV (BSN) has developed a mobile installation (Fig. 6) in which oil-like contaminants are broken loose from soil particles by passing the contaminated soil through a water jet curtain (water velocity: 220 M/sec). Clean soil particles are removed from the resulting slurry by two hydrocyclones. Contaminants are removed in an oil-water separator. The water is recycled to the water jet but has to be replaced daily. The capacity of the installation is about 7.5 m³/hr (12,000 m³/yr).

Although experiences with the unit have been obtained through cleaning contaminated soils at oil refineries (and the cleanup was to the entire satisfaction of the scientists involved), the final concentration of contaminants does not meet the criteria for cleaned soil given by the Dutch government. Recently, redesign of the installation to meet the soil criteria mentioned above was begun.

Flotation

The Heidemij/Mosmans combination has developed a so-called "froth flotation" process (Fig. 7). A pilot-plant installation with a capacity of about 3 m³/hr has been built and successfully utilized with sandy soils contaminated with oil, including some polynuclear hydrocarbons. The installation may also be suitable for treating (sandy) soils contaminated with heavy metals and metalloids, cyanide compounds and chlorinated hydrocarbons. The separated foam is transported to a specialized waste processor. The decision to construct a full-scale installation with a capacity of about 25 m³/hr (40,000 m³/yr) is expected shortly.
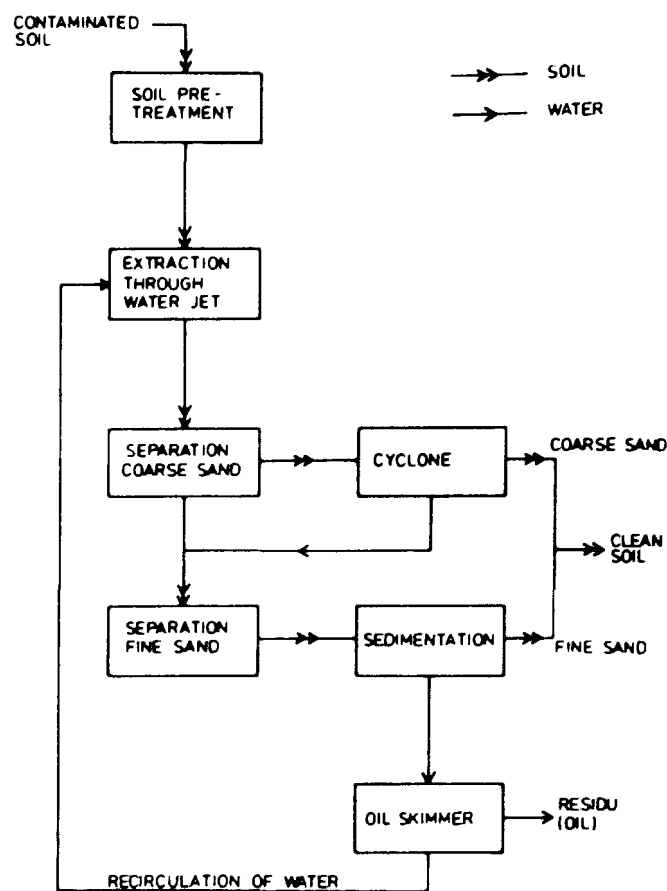
Figure 6
Treatment of Soil by Extraction Through a Water Jet
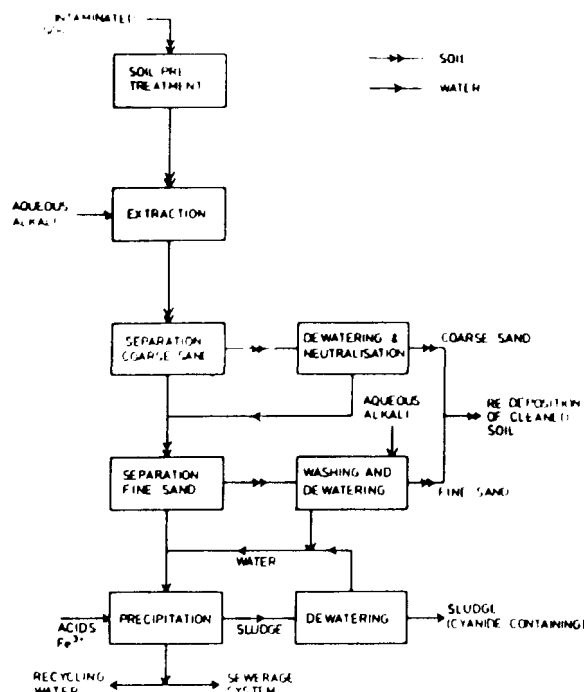
Figure 5
Treatment of Soil by Extraction with an Aqueous Solution
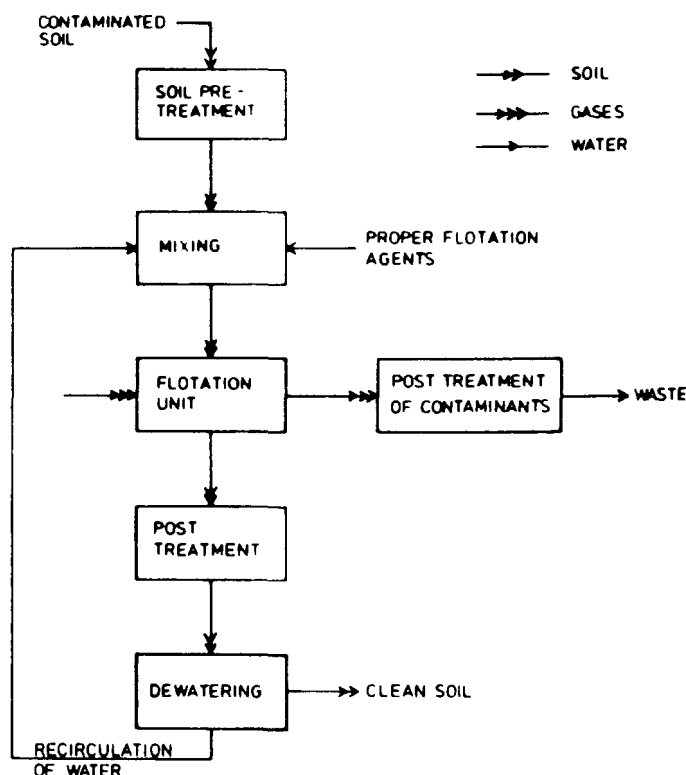
Figure 7
Treatment of Soil by Flotation

Microbiological Treatment

The results of a feasibility study[6] indicate that many organic contaminants in the soil are biodegradable when favorable conditions are created. This general conclusion has convinced the Dutch government to encourage further research in this area. Financial support will be given to research projects designed to determine optimal conditions for the application of landfarming and composting techniques to contaminated soils. In addition, the solution to the particular problem of a considerable amount of soil contaminated with HCHs is studied by the "Rijksinstituut voor Natuurbeheer (RIN)". The preliminary results of this study are quite promising.[7] Anticipating these developments, some contractors already offer full-scale solutions for soils contaminated with oil. Results of applications are not available at this moment.

AVAILABLE TECHNIQUES FOR IN SITU TREATMENT

Thermal Treatment

In the summer of 1983, some tests were performed with the in situ injection of steam in the contaminated Griftpark in Utrecht. No final conclusions on the potential applications of this method can be drawn at this point. Therefore, some additional tests are planned on a sandy soil contaminated with volatile halogenated hydrocarbons. Testing will be limited to the upper 2 m of soil.

Microbiological Treatment

In situ microbiological treatment is in the same situation as microbiological treatment after excavation. The reader is, therefore, referred to the relevant paragraph of this paper on that topic. In addition, the government intends to give financial support to the further development of bioextraction techniques.

CONCLUSIONS

From the preceding paragraphs, it can be seen that the development of remedial action techniques in The Netherlands is quite promising. Additional research, to extend the range of potential applications for the techniques already developed to full-scale installation, will be required. Especially for the clay, peat and stratified soils contaminated with heavy metals and metalloids, no appropriate cleanup technique is available at this time. Since remedial action is urgent while cleanup techniques will be available for most contaminants within a few years. The most promising techniques are those used after excavation as opposed to those employed in situ.

DEFINITIONS

For a better understanding of this paper, some relevant definitions are listed below:

In situ treatment: remedial action leading to the actual removal of the contaminants without any appreciable excavation of the soil.

Treatment after excavation: cleanup of the contaminated soil after it has been excavated to the required degree; the remedial action can take place both on the contaminated site or wherever the required technology is available. In the latter case, transportation of the contaminated soil is necessary.

Containment: remedial action resulting in the prevention of further propagation of the contamination; containment can take place both in situ (geohydrological measures, encapsulation, barriers, etc.) or after excavation (immobilization, waste disposal site, etc.).

Temporary storage: storage of the contaminated soil after excavation awaiting further remedial action; in fact, temporary storage is a specific example of containment.

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EXTRACTION AS A METHOD FOR CLEANING CONTAMINATED SOIL: POSSIBILITIES, PROBLEMS AND RESEARCH

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INTRODUCTION

The remedial methods used to clean up contaminated soil can be broadly divided into two categories:[1, 2, 3, 4, 5, 6, 16, 20]
- Those methods aimed at preventing or restricting the dispersion of the contamination to the immediate surroundings
- Those methods aimed at removing or destroying the contamination

The remedial steps aimed at preventing or restricting the dispersion of the contamination to the surroundings include:
- Excavation of the soil and its transportation to a permanent or temporary storage site. Temporary storage of contaminated soil may be necessary if no suitable method of treatment is available at the time, a method has to be developed or if the supply of soil exceeds existing treatment capacity.
- Restriction of the dispersion of the contamination by installing vertical and horizontal barriers (bitumen membranes, plastic sheets, bentonite-cement walls, steel sheeting, mastic layers, etc.).
- Restriction of the dispersion of the contamination by means of physical or chemical fixation techniques. The soil is treated with chemicals, such as lime, cement, water glass and urea formaldehyde, in such a way that the contaminants in the soil are immobilized to a greater or lesser extent.
- Restriction of the dispersion of the contamination by geohydrological measures (pumping off groundwater and infiltration of fresh water).

The remedial methods aimed at removing or destroying the contamination can be divided into two sub-groups:
- Excavation of the soil and cleaning it on or off-site. These methods are referred to as cleaning after excavation. The most important are:
  - extraction
  - thermal treatment
  - steam stripping
  - chemical treatment
  - microbiological treatment
- On-site cleaning of the soil without prior excavation. These methods are usually referred to as in situ cleaning. The most important techniques are:
  - extraction
  - steam stripping
  - chemical treatment
  - microbiological treatment

The study described in this paper deals with the cleaning of excavated soil by means of extraction. The following topics will be discussed:
- A classification of contaminated soils into types

- A general description of the extraction process
- The equipment which can be used
- Field of application
- The present state-of-the-art
- The problem of residual materials
- The estimated costs of the cleaning process

CLASSIFICATION OF CONTAMINATED SOILS

Obviously, no two cases of soil contamination are identical. Differences in soil contamination cases include: soil type, contaminated site size, site location in relation to inhabited areas, the depth to which the contamination has penetrated, soil permeability, geohydrological situation, nature and concentration of the contaminants, concentration distribution of these contaminants and potential danger to man and the environment.

To evaluate extraction as a method of cleaning contaminated soil, the most meaningful classification of contaminated sites is based on type of soil and type of contamination.

Types of Soil

The different types of soil include:
- Sandy soils, which can be subdivided into soils with a relatively small amount of humus-like substances or clay particles and soils with a relatively high amount of humus-like substances or clay particles
- Loam and clay-like soils
- Peat and peat-like soils
- Soils of a highly heterogeneous composition, i.e., different types of soils are present, usually in layers
- Dumps and other soils; in addition to the actual hazardous contamination, large quantities of urban and/or non-hazardous industrial waste are present. This category also includes contaminated soils under buildings and soils with contaminants in drums.

Types of Contaminants

The types of contaminants which can be encountered in soil can be divided into the following categories:
- Heavy metals and metalloids (e.g., Cr, Co, Cu, Cd, Ni, As, Zn, Sn, Hg, Pb and Sb); these elements are usually present as solid compounds (e.g., oxides, sulphates, sulphides, ferrites, nitrates, halogenides, carbonates, silicates).
- Cyanides, both free (CN^-) and complex (e.g., iron cyanides)
- Aliphatic and aromatic hydrocarbons and related substances (e.g., mineral oil, phenol, toluene, benzene, alcohol, monochlorinated hydrocarbons) and PCBs (polychlorinated biphenyls)
- Pesticides (e.g., lindane, aldrin, dieldrin)

•Other components (e.g., ammonia, acids, lyes, phosphates, sulphates and nitrates)

This classification of contaminations corresponds broadly to the classification used in The Netherlands in the "Table of Test Values" drawn up by the Dutch Ministry of Housing, Physical Planning and Environment.[7]

Contaminant Format

The above-mentioned contaminants can be present in the soil in widely differing forms:

•Present in the form of solid particles; this category includes a large number of heavy metals and metalloids compounds.

•Present as a separate liquid phase, insoluble in water. The liquid phase can be present as drops or as a liquid film around the soil particles; contaminants of this type include mineral oil, petroleum and organic solvents (if they are present in high concentrations).

•Adsorbed physically or chemically as ions to the soil particles (e.g., organic soil components and clay minerals); heavy metals can belong to this category.

•Adsorbed as molecules to soil particles (especially organic); this category can include aliphatic and aromatic compounds (if they are present inlow concentrations).

•Dissolved in the water phase between the soil particles.

GENERAL DESCRIPTION OF THE EXTRACTION PROCESS

Basically, the extraction process consists of three steps (Fig. 1).

•The first step consists of the intensive mixing of the extraction agent and the contaminated soil. The contaminants adsorbed or attached to the soil particles or located between the particles are dissolved or dispersed in the extraction agent.

•The second step consists of the separation of the contaminated extraction agent and soil particles. Separation is usually combined with post-washing of the soil with clean extraction agent in order to rinse out any contaminated extraction agent still present.

•The final step consists of cleaning the extraction agent. The contaminants present are destroyed or separated as a residue, often in the form of a chemical waste. The extraction agent can then be reused.
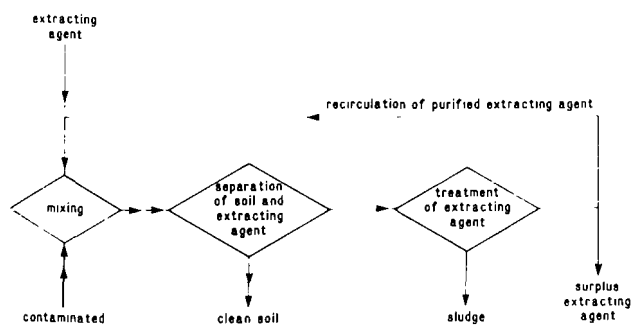
Figure 1
Extraction of Contaminated Soil (Simplified Process Scheme)

Two principal mechanisms of removal can be distinguished in extractive cleaning:

•The contaminants are dissolved in the extraction agent, with or without the aid of a chemical reaction preceding or simultaneous with the extraction.

•The contaminants are dispersed in the extracting phase in the form of particles with or without the aid of prior mechanical treatment. The separation between contaminated particles and soil particles can be based on differences in:

*particle size (sieving)

*sedimentation rate (classification)

*surface properties (selective agglomeration/coagulation and flotation)

In practice, combinations of the above can be used.

A more detailed diagram of the extraction process which includes prior and subsequent treatments is given in Figure 2. In this figure, the following successive steps can be seen (the numbers correspond to those in Figure 2):

1. The soil to be cleaned is pretreated to remove large objects such as pieces of wood, plant remains, concrete, stones, drums, etc., while hard clods of soil are reduced in size. The sieving residue can be cleaned separately.

2. The pretreated soil is mixed intensively with an extraction agent. As already mentioned, the primary purpose of this step is to transfer the contaminants to the extraction fluid.

3. The soil and the extraction agent are separated. In general, the contaminants, the smaller soil particles (clay and silt particles) and the soluble components in the soil are carried off with the extraction agent.

4. The soil undergoes subsequent washing with a clean extraction agent to remove as much remaining extraction fluid as possible.

5. The larger particles carried off with the extract phase are separated as well as possible and, if necessary, undergo a subsequent washing with clean extraction agent.

6. The contaminated extraction fluid is cleaned. Part of it is then reused, after the addition of chemicals if necessary.

It is not always necessary to separate soil particles and the extraction agent before going on to the actual cleaning step for the extraction fluid. With certain types of contamination, the purification step can be applied directly to the suspension of soil particles and extraction fluid. In that case, the separation of the soil particles from the extraction phase takes place after the actual purification step.

Extraction Agents

In general, an aqueous extraction agent is preferred. This preference is based on a large number of considerations, such as:

•Safety of the extracting agent for man and environment

•Prevention of additional groundwater and air pollution

•Natural presence of water in the soil

•Purification possibilities of contaminated extracting agent

•Ease of use

•Costs of the extracting agent

For the efficient operation of the extraction process, it will usually be necessary to add chemicals to the water and/or to heat it. Among the chemicals which can be added are:

•Acids, such as HCl, H_2SO_4 and HNO_3; the primary purpose of these acids is to dissolve the impurities.

•Bases, such as Na_2CO_3 and $NaOH$; the purpose of these substances is either to dissolve the impurities or to disperse insoluble impurities in the extraction phase.

•Surface active agents; addition of these agents aids dispersion.

•Sequestering agents (complex formers) such as citric acid, ammonium acetate, NTA and EDTA; these substances have a positive effect on the solubility of the impurities in the aqueous extracting agent.

In addition to the separate use of the above-mentioned chemicals, combinations of them can also be considered. For example, acids and/or lyes may be used in combination with complex-formers. The extraction process can also be favorably influenced by prior oxidation of the contaminants with the aid of an oxidizer (e.g., hydrogen peroxide or ozone).

In principle, it is also possible to employ organic solvents as extraction agents. This is especially valuable if the contaminants to be removed are not soluble or are scarcely soluble in an aqueous extracting agent and will not disperse in it either.

The organic solvents which are suitable for this purpose fall into two groups: those in which water is soluble and those in which water is scarcely or not soluble. The first category includes acetone, ethyl acetate, ethanol and isopropyl alcohol. Belonging to the second group are the aliphatic hydrocarbons which can be considered as solvents (e.g., hexane). If organic extraction agents are
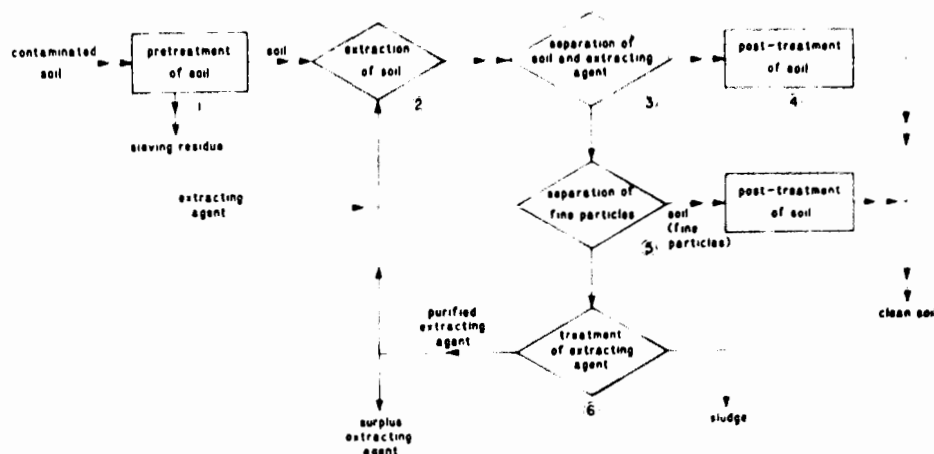
Figure 2
Extraction of Contaminated Soil (Detailed Process Scheme)

used, the cleaned soil must undergo subsequent treatment to ensure that the remaining extracting liquid is wholly or virtually wholly removed.

Cleaning the Extraction Fluid

A large number of physical, chemical and biological purification methods are available to clean a contaminated aqueous extracting agent. Among them are aerobic and anaerobic biological purification, ion exchange, coagulation, flocculation, sedimentation, flotation, membrane filtration, ion exchange, electrodialysis, electrolysis, etc. These methods are extensively used in industry and are described in detail in the literature. Therefore, the individual purification processes will not be dealt with here. For more information, refer to the general literature on this subject.

Which purification process is most suitable in a particular case depends on many factors: the percentage of clay particles and organic components in the soil, the nature and concentration of the contaminants, the composition of the extraction agent and the requirements imposed if the purified extraction agent is discharged into a sewer system and/or into surface water.

In general terms however, the purification process is usually composed of three sub-processes. The first sub-process is aimed at removing the colloidal and suspended particles, e.g., by coagulation, flocculation and sedimentation or flotation. The second sub-process is aimed at removing any dissolved organic components, e.g., by active carbon adsorption. The final step is aimed at demineralizing the extracting agent.

The sludge resulting from the purification of an aqueous extraction liquid is usually dewatered mechanically with a centrifuge, filter press or belt press to minimize the volume of the residue.

For the purification of a contaminated organic extracting agent, one can usually use techniques such as extraction, evaporation, distillation, stripping, etc. These techniques are extensively used in the processing industry. For more information, refer to the relevant literature.

EXTRACTION EQUIPMENT

Basically, many types of equipment are available for the practical application of the extraction process. In general, this equipment is already widely used in the process industry, in wastewater purification or in excavation.

The most critical unit processes in the extraction process are:
• The mixer in which the contaminated soil and the extraction fluid are brought into intensive contact with each other
• The separation system for soil particles and extracting agent
• The purification process for the extraction phase

It will be assumed in the following discussion of suitable equipment that aqueous extraction fluids are employed. This can usually be expected to be the case in practice.

Various systems can be used for the intimate mixing of soil and extraction fluid. In general, these systems involve the generation of high shear forces between the particles and between the particles and the liquid, the object being to scour off the contaminants present on the surface of the particles and to promote solution or dispersion. These high shearing forces can be generated, for example, in a scrubber in which contaminated soil and a relatively small quantity of extraction fluid are mixed intensively by mechanical means. Another possibility for achieving high shearing forces is the use of high-pressure liquid jets. When scrubbers and other mixing equipment are used, it is often necessary to ensure that the mineral soil particles are not crushed. If many small particles result, there can be insurmountable problems in later stages of the soil cleaning process.

Various systems are available for separating the extraction fluid with the impurities in it from the soil particles. The main ones are discussed below.

Settlers

Settlers are usually employed if the settling velocity of the soil particles is sufficiently great and differs from the settling velocity of any dispersed contaminants present. For the efficient operation of the system, several settlers are usually employed in series. Between sedimentation steps, the soil is mixed with relatively clean extracting agent.

Fluidized Beds

A typical fluidized bed is shown in Figure 3. Extraction fluid and soil particles are fed in a counterflow made through a vertical column. The superficial velocity of the liquid is regulated so that the soil particles settle and can be removed at the bottom of the column. The contaminate extraction fluid (including dispersed contaminants and fine soil particles and dissolved soil components) is removed at the top of the column.

Screw Extractors

A diagram of a screw extractor is shown in Figure 4. A screw extractor consists of a sloping trough provided with a transport screw. The soil is fed in at the bottom and transported upwards by the screw. The extraction fluid is fed in at the top and flows downwards as the soil particles flow up the extractor.

Hydrocyclones

The slurry of soil particles and extraction fluid are fed tangentially into the cyclone. The underflow of the cyclone contains the soil particles, still with a small quantity of extraction fluid, while the overflow contains the bulk of the extraction fluid with the dissolved and dispersed contaminants in it. For efficient operation of the system, a number of hydrocyclones are usually placed in series.
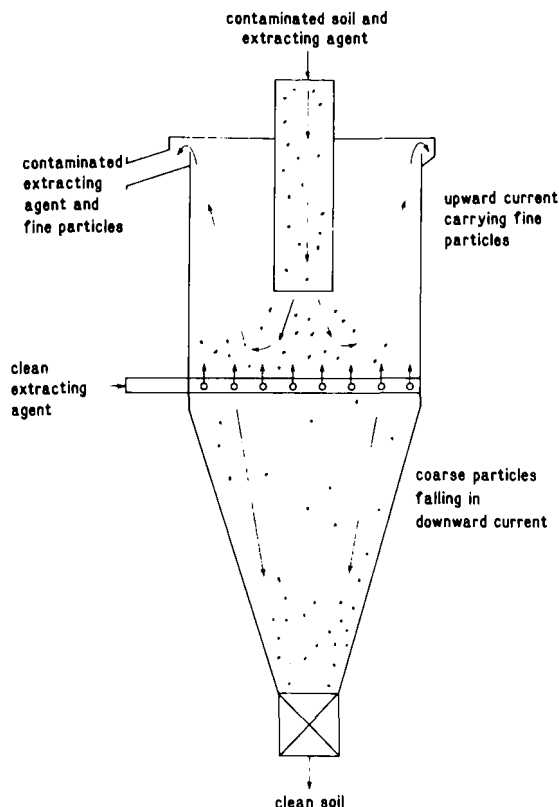
Figure 3
Diagram of a Fluidized Bed

Between the separation steps, the underflow is mixed with (relatively clean) extraction fluid. Hydrocyclones can be employed for the separation of particles down to approximately 20 μm.

In addition to being suitable for the separation of soil particles and contaminated extracting liquid, the above systems can also be used for post-treatment of the treated soil.

Aside from these systems, mention should also be made of a number of other separation systems which are possible but less feasible in practice, such as:

- Vacuum belt filters, or sieve belt filters; the contaminated soil is put on a conveyor belt, which is sprayed with extraction fluid; the percolated extraction fluid is carried off, cleaned and possibly recirculated.
- Rotating liquid sieves; probably only suitable for cleaning soil with particles mainly larger than about 150-250 μm.
- Centrifuges; comparable to hydrocyclones but usually considerably more expensive.
- Sieve bends; only suitable for separating particles larger than 300-400 μm.

Larger particles, still present in the extraction fluid after separation of the bulk of the soil, can be removed using hydrocyclones and/or centrifuges. The process conditions must be designed so that only the larger, relatively clean particles are separated leaving behind any dispersed contaminants which may be present.

FIELD OF APPLICATION

Soil Types

Sandy Soils

The extraction process is best suited to cleaning soils composed mainly of sand particles; it is fairly easy to separate sand particles from the extraction fluid due to their relatively high settling velocity. Separation can be achieved using relatively simple separation equipment, such as settlers. A second reason why the extraction process is highly suitable for cleaning sandy soils is that sand particles have a relatively small specific surface area; thus, the amount of contaminant adsorbed to the sand particles is relatively low.

In the case of sandy soils, both aqueous and organic extraction agents can be used. Which type of liquid is most suitable is determined mainly by the nature of the contaminants. Adequate cleaning of the soil usually can be achieved with an aqueous extraction fluid. The presence of a small quantity of clay particles and/or humus-like substances in the soil imposes no restrictions on the extraction process. It is, however, to be expected that a large amount of clay particles and humus will remain in the extract phase when the soil particles are separated from the extraction fluid and will end up in the sludge of the purification plant.

When sandy soils contain small quantities of humus-like components, the contaminants are often adsorbed to a large extent on these humus materials. Use of an aqueous extraction fluid with a high pH causes some of the humus-like components to dissolve, resulting in fairly easy contaminant dispersion in the extracting agent.

Loamy and Clay-Like Soils

In general, loamy and clay-like soils are much more difficult to clean by extraction than sandy soils for two reasons. First, because of their small dimensions, silt and clay particles readily form a relatively stable suspension with the extraction liquid. This is especially true for aqueous extracting agents with a high pH. If the contaminants are present in the extraction liquid as separate small particles, there is no easy way of separating soil particles from contaminated particles.

The second reason that extractive cleaning is difficult is that many types of contaminants are readily adsorbed by loam and clay particles. This situation applies particularly to the clay particles which readily bind ionogenic components, acting more or less as ion exchangers. Clearly, contaminants which are bound in this way to the soil particles will be difficult to remove.

It is also possible to extract contaminants from clay and clay-like soils with an organic solvent. The application of organic extracting agents appears to offer good prolspects for cleaning soils with organic contaminants which are insoluble in water but are soluble in the organic solvent. However, organic extraction agents generally cost more.

Other Types of Soils

Generally, what has been said about the use of the extraction process with loamy and clay-like soils also applies to peat and peaty soils, highly heterogeneous soils and dump sites. In the case of soils containing large quantities of organic matter (e.g., plant remains and humus compounds), part of this matter will dissolve or become suspended in the extraction liquid. When the extraction liquid is cleaned, these components are separated again and finally end up in the residual sludge.
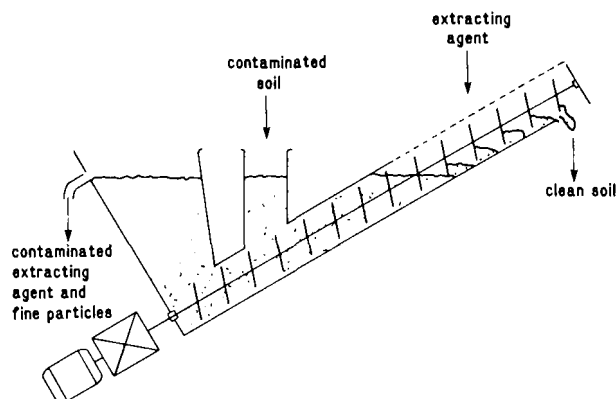
Figure 4
Diagram of a Screw Extractor

Contaminants

Heavy Metals and Metalloids

Two methods are suitable for the extractive removal of heavy metals (and metalloids) or compounds of these elements. In the first method, the metallic compounds are dissolved in the extracting agent. In general, aqueous solutions of HCl, H_2SO_4 and HNO_3 are suitable for this purpose. The action of the extraction agent can be increased by the addition of sequestering agents. In the case of amphoteric metals, it is also possible, in principle, to use a base as the extraction agent. Bases, e.g., an aqueous solution of sodium hydroxide, will generally be preferred because of equipment considerations.

In the second method, the contaminants are removed as solid particles. A base can be used as the extraction liquid. The function of the high pH is to foster the dispersion of the contaminated particles in the extracting agent. Water to which surface active agents have been added can probably also be used for this purpose.

A favorable aspect when lye is used is that a substantial part of the natural organic components (such as plant remains and humus-like compounds) dissolves. When this happens, the contaminants bound to this organic matter also dissolve or are dispersed.

In general, organic solvents seem unsuitable, or in any case less suitable, than aqueous extracting agents for the extraction of heavy metal compounds from contaminated soil.

Free Cyanides and Complex-Bound Cyanides

Free cyanides often dissolve well in lye and can, therefore, be removed by extraction using such a solution. The complex-bound cyanides are usually present as complex-bound iron cyanides. Again, extraction can be achieved using lye which dissolves the iron cyanides.

In general, it can be assumed that organic solvents are not suitable for the removal of cyanides from soil.

Other Inorganic Components

For the removal of contaminants such as acids, bases, phosphates, sulphates and nitrates, aqueous extracting agents are suitable. Here again, a distinction can be made between contaminants which are soluble in water and contaminants which are not.

Organic extracting agents are not usually suitable for the removal of inorganic contaminants.

Organic Components

In principle, aqueous extracting agents are also suitable for the removal of most aliphatic and aromatic hydrocarbons and related compounds such as phenols, alcohols, chlorinated hydrocarbons and PCBs. As in the removal of heavy metals from soil, a distinction can be made here between contaminants which dissolve in the aqueous extracting agent and contaminants which do not. The first category consists of substances such as ethanol and acetone which can often be washed out of the soil easily with cold or hot water free of additives.

To remove contaminants of the second category, it is often necessary to enhance the dispersion properties of the extracting agent by adding lye or surface active agents. Organic solvents can also be used. Which type of solvent is most suitable from a technical and economic standpoint depends largely on the type of contaminant to be removed. It is at any rate important that the contaminant to be removed dissolves well in the solvent.

In summary, extraction is applicable to virtually all types of contaminations. Sandy soils are the most suitable types of soil for cleaning by extraction.

THE PRESENT STATE OF THE ART

The cleaning of excavated soil by extraction is a technique which is still developing. To date, extraction has been used only on a limited scale and for a limited number of types of contaminated soil. In this section, a brief description of the most important developments is given, with the emphasis on processes developed or in use in The Netherlands and the United States.

The Hollandsche Beton Groep NV (HBG) has developed an extractive cleaning plant for sandy soils in cooperation with TNO.[1, 8, 20] The plant has been operational since the summer of 1984 and has a capacity of 25 tonnes/hr. The design is based primarily on the experience obtained with a similar, smaller pilot plant in 1983. A highly simplified diagram of this pilot plant is shown in Figure 5. The following steps occur (the numbers correspond to those in the figure):

1. Pretreatment of the contaminated soil to remove large objects such as pieces of wood and stones and to break up clods.

2. Extraction with lye; the primary object is to scour off the contaminants from the soil particles and to dissolve or disperse them in the liquid phase.

3. Washing of the soil with clean extraction agent in a fluidized bed.

4. The fine sand particles in the extracting agent leaving the fluidized bed are separated in hydrocyclones; if desired, this fine sand fraction can be rewashed separately.

5. Drainage of the cleaned soil through a screen

6. The spent extraction agent containing the contaminants is cleaned in a number of steps. Cleaning usually is carried out by pH adjustment, coagulation, flocculation, sludge separation, sludge dewatering and a second pH adjustment; part of the purified water can be reused.

The plant is primarily designed for sandy soils containing iron cyanides (e.g., gasworks sites). Other types of contamination can also be removed from soil under certain conditions. For example, sandy soils contaminated with arsenic and chlorinated hydrocarbons were successfully cleaned in this pilot plant.

Ecotechniek BV has developed a plant for hot water washing. According to the company, the plant has a maximum capacity of approximately 100 tonnes/hr and is particularly suitable for sandy soils contaminated with oily compounds.[1, 9] For the plant to operate properly, these compounds have to be removed from the sand particles using hot water. In the past, the plant has been used for cleaning beach sand contaminated with crude oil.

The firm Mosmans-Heidemij has developed a flotation process. It was used on a pilot-plant scale in 1983 on sandy soils contaminated with oily materials (including PCAs).[1, 10] A larger plant is expected to become operational this year.

The flotation process is shown diagrammatically in Figure 6. The heart of the plant is a series of flotation cells in which the soil is
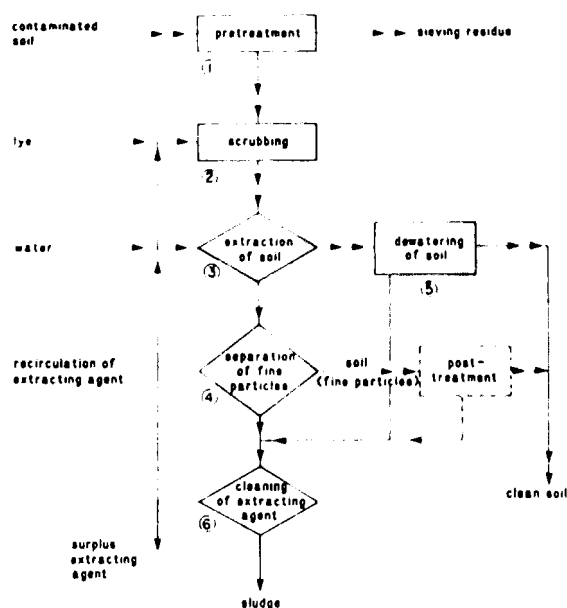
Figure 5
Simplified Process Scheme of the HBG-Extraction Plant
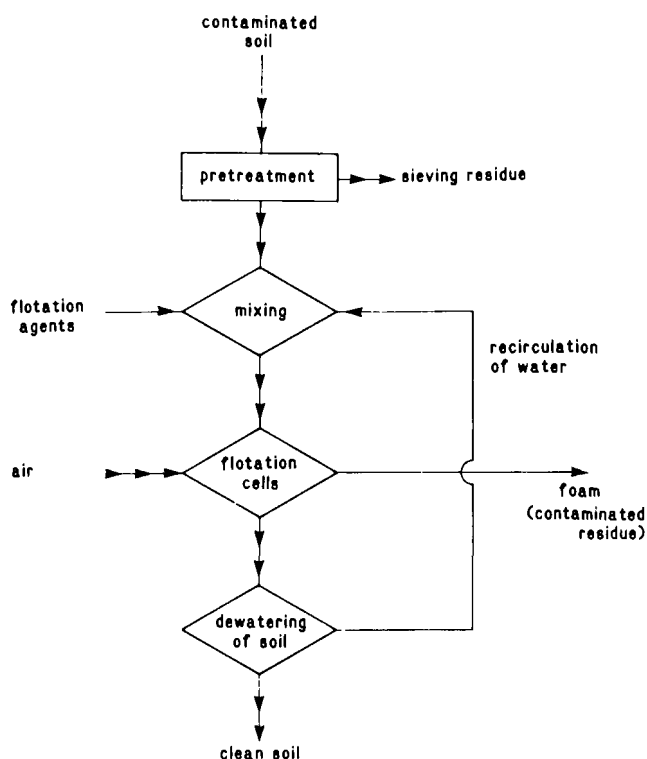
Figure 6
Simplified Process Scheme of the Flotation Process
(Mosmans-Heidemij)

cleaned in two or three steps. The contaminated soil is mixed with water and a small quantity of surface active flotation agents. It is then fed into the flotation cells as a slurry. The function of the flotation agents is to increase the hydrophobic properties of the contaminants. In the flotation cells, air bubbles continually rise, adhering to the slurry contaminants and transporting them to the surface. By skimming off the layer of foam on the surface, separation is effected between the soil and the contaminants.

Although the process is fairly simple in terms of equipment, it is complicated because the cleaning process is sensitive to variations in soil type and types of contaminants. Each contaminated site should be investigated beforehand to establish the optimum process conditions (type of flotation agents, concentration of flotation agents, pH, process times, etc.). In principle, the process seems to be suitable for cleaning sandy soils contaminated with oil products, organic-chloride compounds, heavy metals and cyanides.

Bodem Sanering BV has developed a plant to remove contaminants from soil with high-pressure waterjets.[1, 11] In this plant, which has a capacity of approximately 15 tonnes/hr, soil is transported through a curtain of waterjets with a water velocity of about 220 m/sec. These waterjets detach the contaminants from the soil particles. The method is particularly suited to sandy soils contaminated with substances which are insoluble in water (e.g., oil). A number of successful trials have been carried out.

In cooperation with the Hollandsche Beton Groep NV, TNO has carried out an investigation into the possibility of cleaning sandy soils contaminated with organic bromine compounds such as tribromoethene, tetrabromoethane and higher bromoalkanes.[1, 3, 8, 20] The investigation, carried out on laboratory, semi-technical and pilot-plant scales, resulted in a method of extractive cleaning through which the organic bromine content of the soil was reduced from over 100 mg/kg to less than 1 mg/kg. The design of the cleaning plant is shown in Figure 7. The method of operation generally corresponds to the HBG pilot plant mentioned earlier. However, screw extractors are used instead of fluidized beds, and the method of cleaning the extraction liquid is slightly different.

The above review of extraction cleaning techniques is not complete.[1, 20] It does not include all the Dutch companies and research

institutes which are engaged or wish to engage in extractive cleaning of excavated soil. Moreover, there are presumably developments about which no information has yet been made public.

U.S. Technology

A number of developments in the extractive cleaning of soil are also taking place in the United States. Two plants will be mentioned here.

The USEPA has developed a mobile extractive cleaning plant.[12] The prototype has a capacity of approximately 5 tonnes of soil an hour. The soil is cleaned in four steps in a counterflow made with water as the extraction agent. At each step, the slurry of soil and liquid is intimately mixed in a simple tank by rising air bubbles. The water is purified by activated carbon adsorption, with supplementary purification steps if necessary, and then recirculated. Regarding applications, the plant is said to be usable for many types of contaminants.

A hot water "fluidization" process for cleaning oil-contaminated beach sand was built and tested by the University of California, Santa Barbara, around 1970.[13] The process is a variation of the hot water method used in the Athabasca Tar Sands Deposits and utilizes water at 95 °C in a ratio of 1.2 m³ to 1 tonne of soil in a fluidized, upflow bed contactor. The oil is removed from the fluidized bed with the water overflow and separated from the water in an oil-water separator. The water is recirculated.

Tests performed with a sand mixture containing 1 to 2% of a 23 ° API crude oil showed that more than 95% of the crude oil could be removed. Operation with a 14 ° API residual oil was less satisfactory. The limitations of the process are connected primarily with the range or distribution of sand particle sizes that can be fluidized without excessive elutration.

In the United Kingdom, Robertson Research International Ltd has developed a mobile "dense media cyclone plant" for use on small-scale mining and dump retreatment projects.[14] Separation of contaminants is based on differences in the specific gravity of the particles. This plant can probably also be used for some old, hazardous mine waste sites. The plant has successfully processed a lead/zinc/barite/fluorite prospect and a zinc/fluorite deposit. The capacity is approximately 15 tons/hr.

In Germany, a process for the extraction of heavy metals from dredged materials by an acid treatment has been examined.[15] The method was developed for the decontamination of harbor sediments but is probably also applicable to contaminated soils. This technique, referred to as the "leaching method of Muller," comprises three steps: (1) an acid treatment with HCl to extract heavy metals; (2) separation of the solids from the solvent; and (3) the removal of the heavy metals from the extracting agent by a hydroxide and carbonate precipitation.

PROCESSING OF RESIDUES

When soil is cleaned by extraction there is always a residue containing concentrated contaminants. This residue often must be treated as a hazardous waste. If an aqueous extraction agent* is used, the residue comes free as a sludge. In addition to the actual contaminants, the sludge usually contains a high percentage of clay particles and organic soil components (such as plant remains and humus-like compounds). The fraction of such matter in the sludge is generally many times higher than that of the contaminants. The amount of sludge produced per tonne of treated soil, therefore, largely depends on the composition of the soil. The amount of sludge is also affected by the type of purification process used for the spent extracting agent: whether chemicals have been added and the way in which water is removed from the sludge are particularly important.

Further processing of the sludge, regarded as a hazardous waste, can occur in two ways. The first method involves the transportation of the sludge to a controlled disposal site. Here, the sludge

*This section deals exclusively with residues resulting from cleaning with an aqueous extraction agent.
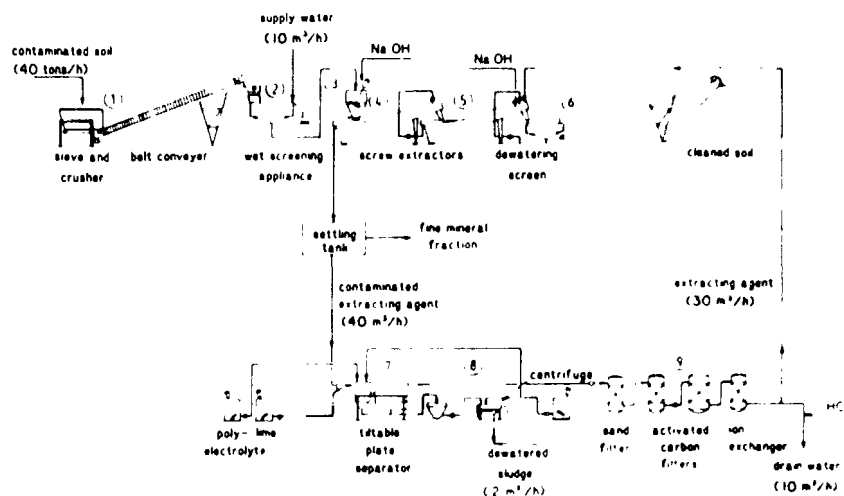
Figure 7
Process Scheme of the Proposed On-Site Treatment Installation for Removal of Organic Bromine Compounds

can undergo chemical or thermal treatment to immobilize the contaminants to a greater or lesser extent. Transportation to a controlled disposal site will be necessary if no (economically feasible) processing method is available. The second possibility for sludge handling is to further concentrate and/or destroy the contaminants. In principle, various techniques are suitable.[17, 18] Most of them are also used, or can be used, for the processing of other types of chemical waste. The most important techniques are:

•Incineration
•Chemical oxidation with the aid of hydrogen peroxide, ozone, potassium permanganate, sodium hypochlorite and calcium hypochlorite
•Hydrolysis in an aqueous environment at increased temperature and pressure; this process is usually carried out in an acidic (sulphuric acid or hypochloric acid) or an alkaline (caustic soda or caustic potash) environment.

The aim of the first two processes is the complete oxidation of the contaminants. The last process is designed to decompose the contaminants chemically to smaller molecules. The process can be aided by the addition of oxygen. Treatment in an aqueous environment at elevated temperature and pressure with the addition of oxygen is known as wet air oxidation. However, hydrolysis does not necessarily result in substances less toxic to man and the environment than the original contaminants.

The success of the above-mentioned methods of treatment of different types of sludge is discussed in the next four sub-sections.

Sludges Containing Heavy Metals (and Metalloids)

Basically, destruction of heavy metals is impossible. A substantial reduction of the volume of the residual sludge can be achieved by incineration. In the incineration of a heavy metal-containing sludge, attention must be paid to the evaporation of heavy metals. A number of heavy metals (or metalloids) easily evaporate (e.g., mercury, arsenic and cadmium) and have to be removed from the exhaust gases.

A general problem in the incineration of sludges obtained in liquid extraction of contaminated soil is the entrainment of small particles by the exhaust gases. These particles can be primarily comprised of heavy metals and consequently have to be removed from the exhaust gases.

Sludges Containing Free Cyanides

Free cyanides can be destroyed by chemical oxidation (e.g., by sodiumhypochlorite). A precondition, however, is that the cyanides are more or less soluble in an aqueous liquid. For cyanides, insoluble in cold water, thermal treatment methods such as hydrolysis at higher temperatures and incineration are probably the most promising methods.[19]

Incineration should occur under strictly controlled process conditions (excess oxygen, relatively long residence time in the afterburner, high temperature to avoid the formation of toxic components. Adequate safety control measures should be taken to avoid calamities. As far as known, there is little large scale experience with these methods.

Sludges Containing Complex Cyanides (Iron Cyanides)

From the literature, it appears that both hydrolysis and incineration are applicable when the right process conditions are chosen.[17, 18, 19] The incineration process is possible using a high temperature, excess oxygen and a relatively long residence time in the afterburner. Hydrolysis is possible at temperatures of 250°C and higher and a residence time of several hours. However, practical experience on a large scale is not yet available.

Sludges Containing Organic Compounds

Incineration currently appears to be the most appropriate treatment method. This is especially true when different types of organic contaminants are present in the sludge. Incineration is an especially attractive method for treating sludges containing large amounts of oily compounds.

The incineration conditions depend mainly on the types of contaminants. In general, halogenated hydrocarbons (e.g., PCBs and pesticides) require more stringent conditions of incineration than simple aliphatic compounds (e.g., oil).

Numerous organic hazardous wastes are currently being destroyed by incineration on a large scale world-wide. The knowledge and experiences gained in this field will be very valuable for the incineration of residual sludges from the extraction of soils contaminated with organic compounds.

It is also known that a large number of organic hazardous waste compounds can also be destroyed by wet air oxidation.[18] However, at this moment there is a lack of practical experience on a large scale.

Finally, it has to be noted that pre-treatment of the sludge by neutralization, drying, oxidation, milling or stripping of volatile compounds can sometimes increase the technical and economic applicability of the above-mentioned treatment methods.

COSTS

The costs of cleaning a given quantity of contaminated soil by extraction depend greatly on the type of soil, the nature of the contamination and the desired degree of cleaning. The principal cost factors include:

•Cost of the extracting agent* (chiefly the cost of chemicals to be added

*In this section only aqueous extracting agents are considered.

- Cost of cleaning the extracting agent
- Cost of further processing and/or disposal of the residual sludge
- Energy costs
- Costs of transport, construction and dismantling the purification plant
- Interest and depreciation costs of the plant
- Labor costs
- Costs of analyses for process control
- Costs of any additional measures (in connection with safety, prevention of groundwater and air pollution and prevention of a noise nuisance)

Of the above factors, interest on, and depreciation of the investment are by far the most important. These costs depend greatly on the number of hours per annum that the plant is in operation. Other important cost factors are labor costs and the cost of processing and/or disposal of the residues.

On the basis of the experience obtained with pilot plant investigations and actual cleanup operations, the costs of extractive cleaning are estimated at $20 to $75 (U.S.)/tonne of soil treated. In view of the lack of sufficient practical data, this cost estimate should be regarded as approximate.

CONCLUSIONS

Extraction can be considered to be a technique which is capable of removing all types of contaminants from soil, provided the contaminants can be sufficiently transferred to the extracting agent. Thus far, the applicability of the technique has been investigated only for the cleaning of sandy soils with an aqueous extraction fluid. Favorable results have been obtained for a number of contaminants, including complex (iron) cyanides, aromatic hydrocarbons, oily compounds and organic bromine compounds.

The quantity of residual sludge formed in the extraction process can be a problem. This sludge, in which the contaminants are concentrated, must generally be regarded as a hazardous waste. Additional costs are usually associated with the processing of this waste in order to destroy the contaminants or substantially reduce the quantity of waste.

The principal techniques available for processing residual sludge are incineration, chemical oxidation and hydrolysis. Practical experience on a large scale has been obtained only with incineration.

Very roughly, the costs of extracting contaminants from sandy soils are estimated at $20 to $75 U.S./tonne of soil.

Of the various techniques for cleaning contaminated soil, the ones which are most developed and have the widest application are extraction and thermal treatment. Although the areas of application of the two techniques partially overlap, extraction is probably the only cleaning technique suitable for soils contaminated with heavy metals.

To further technical and economic optimization of the extraction process and widen the area of usefulness, research is needed in the following areas:
- Minimization of the quantity of residual sludge formed
- Processing of residues from the extraction process. For example: thermal treatment of sludge containing iron cyanide; hydrolysis of sludge containing iron cyanide; thermal or hydrolytic treatment of sludge containing halogenated hydrocarbons (e.g., PCBs and pesticides).
- Extraction of loamy and clay-like soils
- Extraction of peat and peaty soils

- Development of processes in which organic extraction agents can be used. Attention will have to be paid not only to the choice of organic extraction agents but also to the treatment of the spent extraction agents.

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MEASUREMENT OF LOW PERMEABILITY COEFFICIENTS BY MEANS OF ELECTRONIC INSTRUMENTS

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INTRODUCTION

For determining the permeability coefficient (k_f) of non-cohesive soils, there is a great variety of methods which have been used in the laboratory for decades. However, the study of the water-permeability of cohesive soils with low permeability coefficients poses problems.

Low permeability coefficients are an important criterion for constructing waste sites. The Institute for Applied Geology of the Westphalian Mining Fund is often involved in investigating potential disposal sites and assessing them. This process requires determination of the permeability coefficients of very slightly permeable soils.

In order to study permeability coefficients of slightly permeable soils ($k_f = 10^{-7}$ m/s to $k_f = 10^{-11}$ m/s), the Institute for Applied Geology had intended to acquire suitable laboratory apparatus. Intensive efforts to acquire a measuring device from reputable laboratory equipment makers both at home and abroad were unsuccessful. They therefore decided to construct a measuring device.

REQUIREMENTS FOR THE MEASURING DEVICE

The following requirements were established:
- Measurement of small permeability coefficients
- Automatic recording of the measurements
- Simulation of the specific overburden pressure
- Simulation of high pore water pressures
- Simulation of high pore water pressure differences

DESCRIPTION OF THE MEASURING DEVICE

The measuring device consists of a consolidation cell, a consolidation press, a water tank, recording equipment, a computer and two displacement transducers (Fig. 1). The soil sample is placed in the pressure cell and is loaded by the press. The consolidation of the sample is recorded with the help of a transducer.

Water is forced up through the sample from below, under known pressure from a cylindrical tank with variable volume (piston). The volume of water flowing through the sample is determined by the free cross-section of the tank and the displacement of the piston. The displacement of the piston is measured by means of an electrical displacement transducer. The pressure on the soil sample and the water pressure can be continuously controlled by the recording equipment and measured by pressure transducers. Additionally, the water temperature at the sample is measured (Fig. 2).

In order to measure the permeability of contaminated water as well, the consolidation cell and the water tank were constructed of stainless steel.

All the measurements of the recorder are fed into the computer at regular intervals by means of a time switch. The calculator is programmed to calculate the permeability coefficient automatically from these measurements.
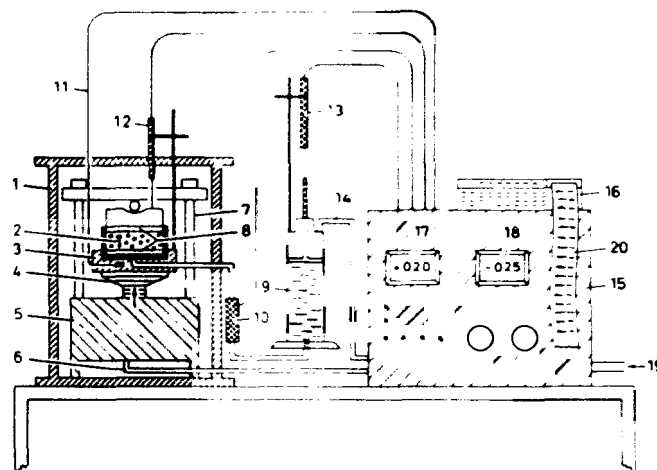
Legend

1. Frame (tiltable through 90° and 180°)
2. Sample
3. Consolidation cell
4. Plunger plate
5. Pressure cylinder
6. Compressed air line to pressure cylinder
7. Consolidation press frame
8. Filter plates
9. Cylindrical tank
10. Pore pressure gauge
11. Temperature gauge
12. Displacement transducer for measuring the consolidation of the sample
13. Displacement transducer for measuring the volume of water flowing through the sample
14. Compressed air line to cylindrical tank
15. Recording equipment
16. Computer
17. Indicator for the pore pressure gauge (10), temperature gauge (11), displacement transducer on cylindrical tank (13), switchable
18. Indicator for the pressure of the consolidation press
19. Compressed air line (inlet)
20. Paper strip (results)

Figure 1
Diagrammatic Sketch of Measuring Device for Water-permeability.
(designed by Birk, Coldewey, Geiersbach for the Westphalian Mining Fund.)
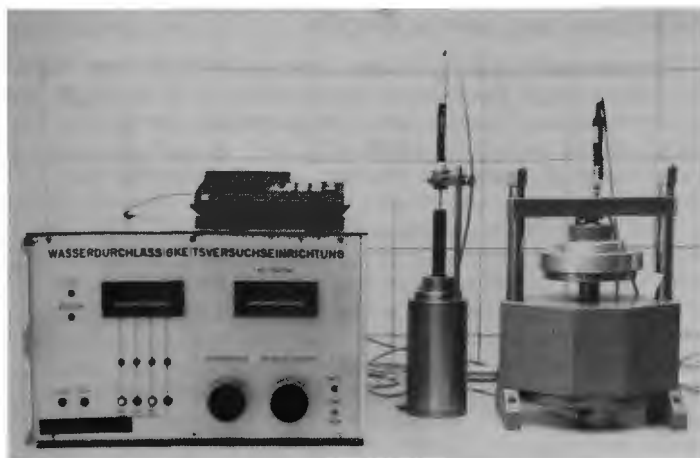
Figure 2
Photograph of the Water Permeability Measuring Device

ADVANTAGES AND DISADVANTAGES OF THE METHOD

The measurement of the permeability coefficient by means of electronic instruments offers numerous advantages.

With this measuring device, a large number of samples can be quickly processed. The equipment is completely self-sufficient and can be used over extended periods.

Furthermore, the method permits the simulation of an overburden pressure—in a continuous manner—to a depth of 200 m. This option is especially important since the permeability coefficient varies with depth.

A further advantage of the equipment is that one may control very closely over a wide range of pore pressures and thereby control the hydraulic gradient at the cell-inlet. The range of available pressures is between 5 and 80,000 cm of water at a sample length of 2.5 cm. Using this capability, one can ascertain at which pore pressure the permeability coefficient tends towards zero, where the transition point from the pre-linear zone to a linear one occurs, or at what point a turbulent flow (post-linear range) or similar behavior arises. In fact, it would also be possible to ascertain where the sample approaches hydraulic soil failure and at what point it is eventually reached.

Finally, one should note that the flow through the sample can be from the top, from the bottom or horizontal. This change in direction can be achieved by rotating the consolidation cell in a frame. This capability is important because the direction of flow affects the permeability coefficient.

A disadvantage of utilizing electronic instruments is that logging the results—as compared with other processes—is removed from the direct control of the operation.

CHECKING THE MEASURING DEVICE

Intensive experimentation was undertaken before putting the apparatus into use.

Pressure Transducer

To check the consolidation press, a calibrated testing ring was incorporated in the consolidation cell frame. The pressure on the frame was measured in two ways:
- By means of a dial gauge on the testing ring
- By means of a pressure transducer with electronic indicator on the recorder of the permeability apparatus

Comparison of the two series of measurements showed a linear relation between the values derived by the different two procedures.

Since the compressive stress on the sample surface as well as the absolute force, is of interest, the compressive stress (σ) in N/mm^2 was also calculated (Fig. 3). Under natural conditions this stress depends on the thickness (h) and density (ρ) of the overburden.

$$\sigma = \rho \cdot g \cdot h \tag{1}$$

To simulate the overburden pressure at the consolidation cell, the thickness of the overburden with densities $\rho = 2$ or $2.2 \ g/cm^3$ was calculated and is shown on the lower abscissa (Fig. 3). The available consolidation press can simulate overburden pressures up to 200 m.
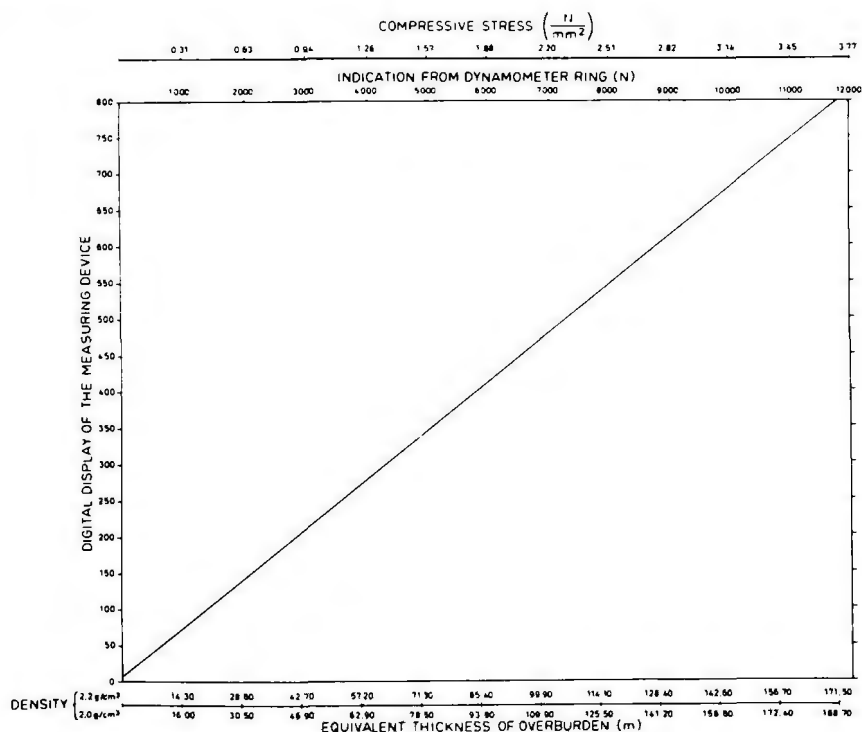
Figure 3
Checking the Pressure Transducer on the Consolidation Press and Converting for the Specific Overburden Pressure

Pressure Transducer

The pressure transducer on the water tank was checked with a calibrated manometer. The measured values were fully in agreement with those shown on the recorder of the apparatus.

Electronic Displacement Transducers

The displacement transducer on the water tank was checked with a dial gauge. The results are shown in Figure 4. The small variations of the measured values arise from inaccuracies in the mechanical dial gauge, as was apparent when the dial gauges were compared.

Then the displacement transducer on the press was compared with the one on the water tank. Here, too, there was complete agreement.

Volumes of Water

The volume of water that flows through the soil sample is calculated from the free cross-sectional area of the water tank and the electronically measured displacement of the piston. The water emerging from the sample was collected and weighed. Comparison of the results of these two processes showed complete agreement (Fig. 5).

Computer Program

The data were processed with the aid of a Hewlett Packard HP 97 programmable desk computer. The functions of the computer can be checked with a test program. This checking of the computer is performed at regular intervals.

Checking the program on magnetic cards is also necessary, since the programs, too, can be disturbed by external causes (e.g., magnetic fields).
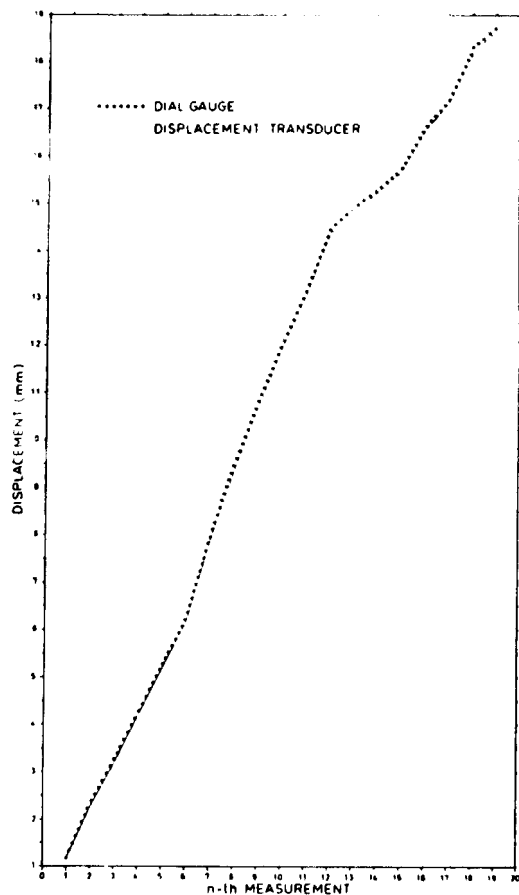
PROBLEMS AND APPLICATIONS

The equipment can be readily operated with the help of an operating manual. Errors can arise only when, at the beginning, the pore pressure and then the consolidation pressure are applied. The sample can be pressed out of the cell.

The range of application lies between approximately $k_f = 1 \cdot 10^{-6}$ m/s and $k_f = 1 \cdot 10^{-11}$ m/s. Results may be obtained within an hour; in fact, even quicker at values such as $k_f = 1 \cdot 10^{-6}$ to $k_f = 1 \cdot 10^{-8}$ m/s. From $k_f = 1 \cdot 10^{-10}$ to $k_f = 1 \cdot 10^{-12}$ m/s, approximately 1 day is required to get useful results. Permeability coefficients smaller than $k_f = 1 \cdot 10^{-12}$ m/s can only be determined by rough approximation.

Reproduceability between $k_f = 1 \cdot 10^{-6}$ m/s and $k_f = 1 \cdot 10^{-9}$ m/s is high up to the decimal point. This was proven with isotropic samples. However, the accuracy drops as values approach $k_f = 1 \cdot 10^{-11}$ m/s, where it becomes only half of a power of ten. Beyond that k_f value, one can only estimate results within an order of magnitude.

Inaccuracies or errors arise through evaporation of the pore water. This loss of water causes superficial drying-out of the sample. As a result, more water gets transported through suction than through the actual flow. This problem becomes more serious near the boundaries, since the process is always accompanied by a temporary shrinkage of the sample in this zone.

To avoid this phenomenon, the complete cell is placed in a water-bath, thereby eliminating the suction pressure. This step will help to avoid the above mentioned inaccuracies.

Dye tests have shown that boundary flow can be ignored. Even in non-cohesive materials, the flow velocity, in the immediate vicinity of the boundary, is only 1/3 higher than in the rest of the sample. Thus, calculated over the surface, this phenomena can be ignored.

Figure 4
Results from Testing the Displacement Transducer
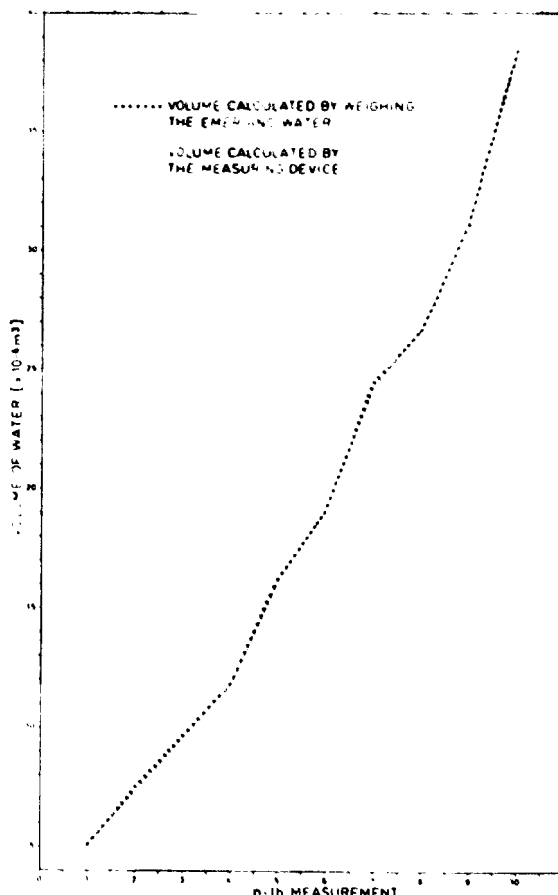
Figure 5
Results from Comparison of Measured and Calculated Volume of Water

TEST RESULTS

One may best interpret the results by comparing results with measurements made using different equipment. Samples were exchanged with the Niedersachsisches Landesamt fur Bodenforshung NLfB (Lower Saxony Geological Survey).

A permeability coefficient of $k_f = 1 \cdot 10^{-7}$ m/s was obtained for pure quartz dust using the measuring device of the Westphalian Mining Fund with a consolidation pressure of 0.5 kg/cm^2 and a pore pressure higher than 0.1 bar; the value obtained by the NLfB was $k_f = 1.6 \cdot 10^{-7}$ m/s. For other quartz dust samples at higher overburden pressures, the agreement was as good. A greater difference was obtained when natural samples were compared. It appears that the error occurred because a more jointed sample was put into the measuring device, which then yielded a higher permeability coefficient.

EXTENSION OF THE MEASURING DEVICE

To further improve the accuracy when studying highly cohesive soils, one may use a narrower water tank. At the other end of the scale, a larger water tank is used for permeability coefficients above $k_f = 1 \cdot 10^{-6}$ m/s.

Additionally, new pressure transducers and displacement transducers with more precision were installed. In order to test samples of different length, a longer consolidation cell was also constructed.

CONCLUSIONS

In conclusion, one can say that the measuring device enables the following:
- Measurement of permeability coefficients from $k_f = 10^{-6}$ m/s to $k_f = 10^{-12}$ m/s
- Measurement of flow from the top, the bottom and horizontally
- Simulation of overburden pressure
- Simulation of high pore water pressure
- Simulation of high pore water differences

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THE UPWARD MIGRATION OF CONTAMINANTS THROUGH COVERING SYSTEMS

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INTRODUCTION

The majority of contaminated land sites or landfills in the United Kingdom are isolated or encapsulated. This sometimes requires the use of several layers of cover materials. The covering systems are likely to be required to perform three main functions:
• To prevent exposure of the population at risk
• To sustain vegetation
• To fulfill an engineering role such as accommodating uneven settlement, trafficking, etc.

The ability of any covering system based on soil or soil-related minerals to fulfill the above functions will depend on a number of factors.[2]
• Control of upward and lateral migration of contaminants through the ground

• The ability of the cover material to immobilize pollutants through chemical and physical absorption
• Its effectiveness to control water ingress and thus leachate production
• The interaction between covering systems, the contaminants and the biology, e.g., plant root systems
• The engineering behavior of the system and its component materials

In this paper, the authors describe two investigations in which constructed soil columns were used to assess the upward migration of contaminants from contaminated ground into clean imported barriers and covers.

In experiment 1, the columns contained a lead/zinc waste which was covered by various barriers and topsoil. In experiment 2, various wastes arising from the coal carbonization process were covered by compacted clay and topsoil.

LEAD/ZINC WASTE EXPERIMENTS

Materials and Methods

Soil profiles were constructed in 30 cm diameter PVC columns. The columns contained 30 cm of topsoil overlying a 30 cm barrier layer placed on the waste (Fig. 1) to simulate a minimum treatment for land reclamation.[1] The barrier layers consisted of materials which are commonly used for this purpose in the United Kingdom: sea-won sand, land-won sand, clay, pulverized fuel ash (PFA) and building rubble. The waste, from a former lead/zinc mine, contained lead, 32.9 mg/g; cadmium, 0.425 mg/g; and zinc, 56.6 mg/g, at pH 7.4. Each column treatment and a control, consisting of a column completely filled with topsoil, were replicated three times, resulting in a total of 18 columns.

The topsoil was sown with a mixture of perennial ryegrass and white clover, which is a common seed mixture for amenity grassland. The columns were maintained in drought conditions and received only sufficient water to sustain vegetation growth. All columns were maintained with a constant water table at the base. The replicates of each treatment were randomized in a polyethylene tunnel at the University of Liverpool Botanic Gardens, Ness, in April, 1980, and monitored continuously until dismantled after 30 months. The establishment of the columns has been described previously.[1]

Soil samples, taken at 5 cm intervals up the column, were collected at the end of the experimental period and analyzed by atomic absorption spectrophotometry. The distribution of plant roots at 5 cm intervals was also assessed.
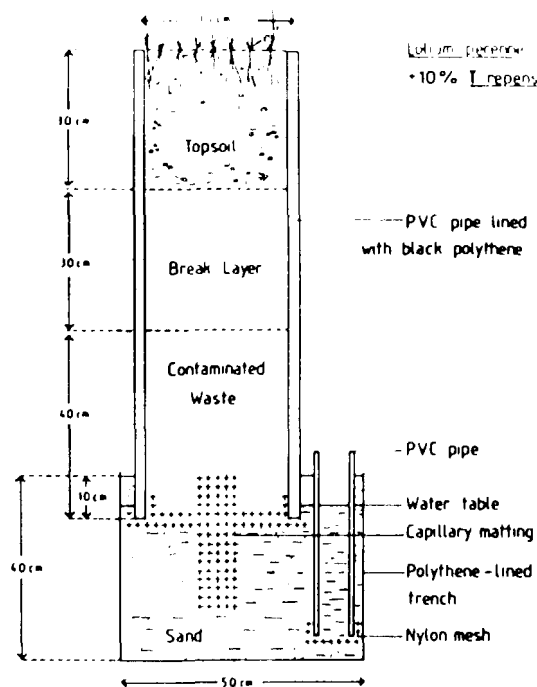
Figure 1
Section of Single Column
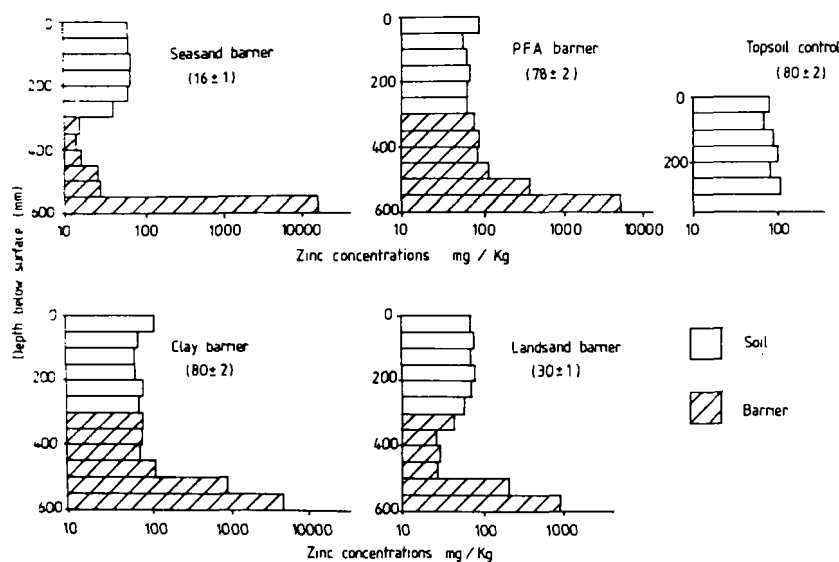
Figure 2
Zinc Concentrations (original concentrations) in Barriers Overlying Contaminated Waste, Kept Under Drought for 30 Months.
N.B. It Was Not Possible to Sample the Building Rubble Barrier
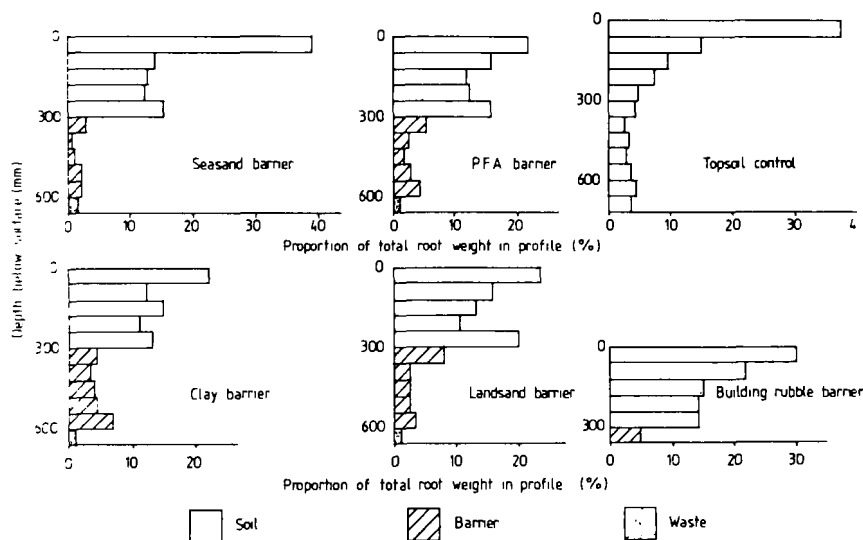
Figure 3
Plant Rooting Pattern in Topsoil and Various Barriers Overlying Contaminated Waste, Kept Under Water Stress for 30 Months

Results and Discussions

Changes in the concentrations of lead, zinc and cadmium were found within the barrier layers after the 30 month experimental treatment. In all cases, however, the barriers prevented transfer of metals to the topsoil. The largest increase in metal concentrations in the barriers was found in zinc concentrations immediately above the waste (Fig. 2) in the clay and PFA barriers where zinc had increased from 80 to 5860 mg Zn/kg and from 78 to 6620 mg Zn/kg respectively.

The patterns of lead and cadmium in the barrier layers were similar to that for zinc, but less obvious. Small increases in cadmium concentrations occurred only in the lower 5 cm of the barriers; again, greatest increases occurred in the clay and PFA barriers. Increased lead concentrations were found in the first 10 cm above the waste. At the end of the experimental treatment, the plant root distribution at 5 cm intervals was assessed (Fig. 3).

In general, the root distribution in all soil columns was similar and, as expected, decreased with depth from the top of the column until the barrier layer was encountered. Some rooting took place in the barrier but little occurred into the waste. In the clay and PFA barriers, and to some extent in the land/sand barrier, increased rooting occurred at the base of the barrier and immediately above the waste. Zinc concentrations in the established vegetation were also affected by the 30 month experimental treatment, with the clay treatment showing most uptake (Fig. 4).

COAL CARBONIZATION WASTE EXPERIMENT

Materials and Methods

Soil columns similar to those described in the first experiment were established in August, 1982, within a polyethylene house at the University Botanic Gardens.
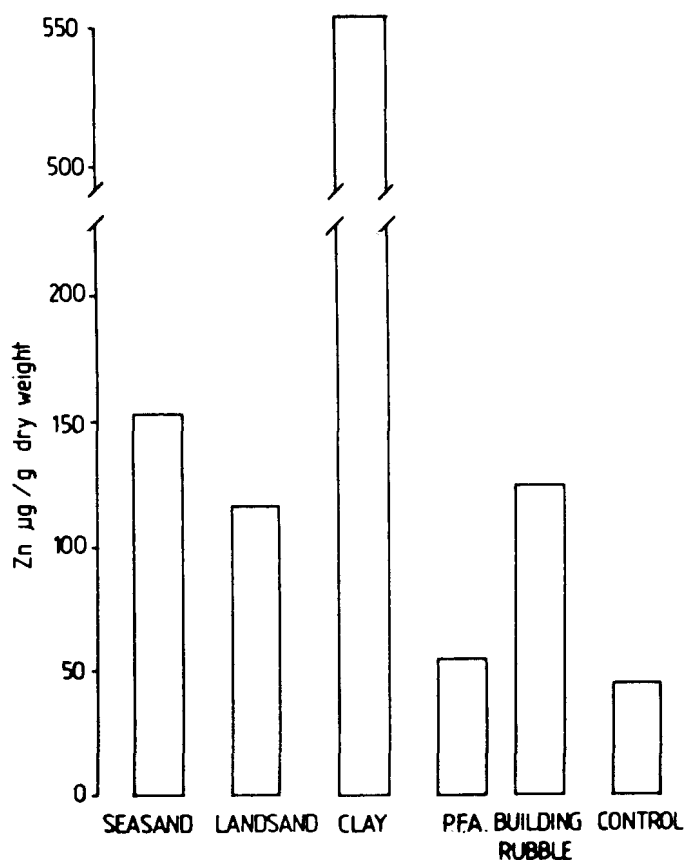
Figure 4
Zinc Concentrations in Plants

They contained 40 cm each of:
- Spent oxide covered by clay and topsoil
- A 50/50 mix of clinker and spent oxide wastes covered by clay and topsoil
- High sulphate waste covered by clay and topsoil
- Clinker and tarry waste covered by clay and topsoil

These wastes are described in Table 1.

During the filling of the columns, each soil or waste layer was "tamped" down. Additionally, care was taken to fill the columns evenly. Finally, all columns were sown with ryegrass and white clover mixed in a ratio by weight of 9:1 and sown at a rate of 1.4 g per column, which approximates 50 kg/ha.

The establishment of the water table beneath the wastes, and thus the watering of the columns from beneath, was commenced on Aug. 2, 1982. From this date on, no water was applied to the top of the columns except when the established sward showed signs of wilting. Sufficient water was then applied merely to remedy this situation.

At the beginning of August, 1983, after exactly 12 months of treatment, one replicate of each of the four experimental treatments was dismantled. The PVC columns were cut longitudinally and the two halves separated to reveal the soil column. To ensure that edge effects did not bias sampling, this section was also halved longitudinally in order that the center of the soil core could be obtained. Five soil samples were taken from each column:
- Waste material
- Clay immediately above the waste/clay interface
- Clay immediately beneath the clay/topsoil interface
- Topsoil immediately above the clay/topsoil interface
- Topsoil at the top of the column immediately beneath the grass sward

All samples were then analyzed.

Chemically, the cyanide ion behaves the same as the chloride ion; it would therefore be expected to be only very weakly bound within
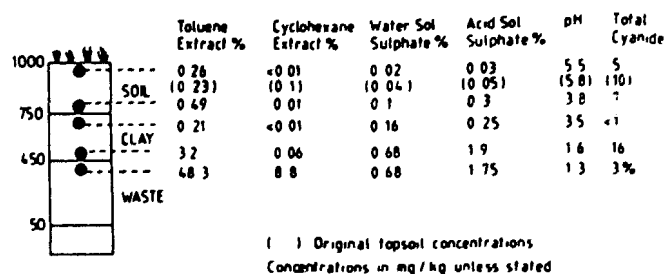
Figure 5
The Spatial Relationship of the More Significant Contaminants with the Soil Column Containing Spent Oxide
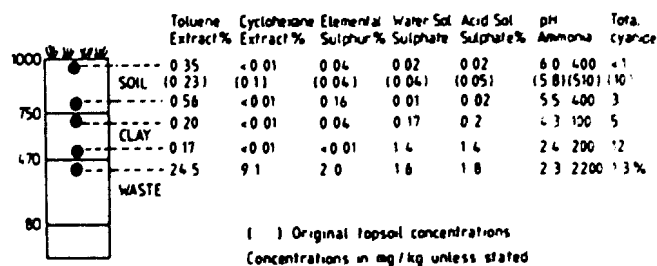
Figure 6
The Spatial Relationship of the More Significant Contaminants within the Soil Column Containing Clinker and Spent Oxide
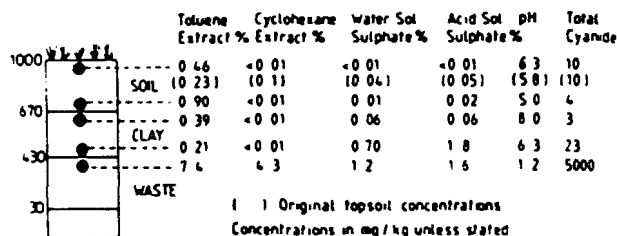
Figure 7
The Spatial Relationship of the More Significant Contaminants with the Soil Column Containing Sulphate Waste
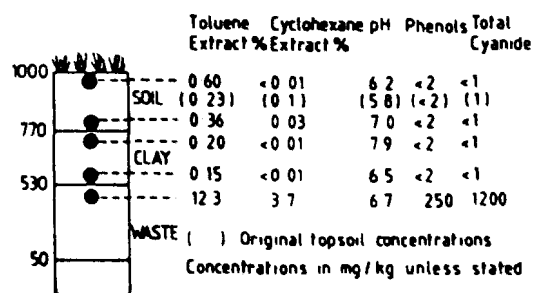
Figure 8
The Spatial Relationship of the More Significant Contaminants with the Soil Column Containing Clinker and Tar

the soil matrix and thus would be likely to migrate. This was, however, not shown (Figs. 5 to 8). Some cyanides at low concentrations are biodegradable, and it is possible that this has masked any increase in concentration up the column.

Only one experimental column contained significant quantities of phenols (Fig. 8), and under the conditions of this experiment they did not appear to migrate. The rooting densities at various

Table 1
The Original Analytical Details of the Wastes Used in the Second Experiment Involving Tarry Wastes

	Sulphate waste	Clinker & spent oxide	Tarry waste	Spent oxide
	0	0	0	0
pH %	1.4	2.4	5.4	2.0
Acid Sol. Sulphate %	6.1	3.3	0.36	5.3
Water Sol. Sulphate %	3.88	2.3	0.07	2.71
Elemental S %	11.6	32.3	0.11	48.3
Sulphide	4	4	11	5
Total CN	6333	467	53	3%
Free CN	17	---	---	---
Phenols	3	< 2	727	< 2
Ammonia	860	2700	443	5430
Toluene extract %	13.8	35.8	7.0	60.6
Cyclohexane extract %	1.7	1.7	2.6	2.0
Coal tar	< 500	< 500	5.7%	< 500
Pb	180	529	1823	63
Zn	47	181	350	50
Cd	0.1	0.7	1.3	0.3

Note: All Concentrations in mg/kg except those specified in %.

depths down the soil columns are shown in Figure 9. As expected, the vast majority of roots were found in the topsoil, but the rooting density decreased with depth down the column. Some roots did penetrate all wastes; in particular, the clinker and spent oxide waste.

DISCUSSION

Under the experimental conditions utilized, contaminants have been shown to move into constructed barrier layers from underlying contaminated materials. In the first experiment, significant concentrations of zinc moved 10 cm upwards into both clay and PFA barriers over the 30 month experimental period. In the second experiment, acid and water soluble sulphates moved 40 cm through a clay barrier over the 12 month experimental period. Other contaminants, such as lead, cadmium, cyanides, phenols and coal tars, did not move as far. Such upward migration has also been identified in attempts to reclaim metalliferous tailings. In British Columbia, a gravel layer was needed to stop upward migration of acids, soluble salts and iron aluminum zinc and copper into imported overburden.[3]

Upward migration has occurred because of various related factors: the texture, structure and compaction of the barrier layers has allowed capillary rise, and the evapotranspiration of the established vegetation has created a net moisture deficit in the upper soil levels. The optimum barrier material within a covering system intended to prevent upward migration of contaminants should therefore have a large particle size so that the large pore sizes will tend to break any capillary rise.

The materials or soils above this barrier should be of sufficient depth and water holding capacity to be able to fulfill any needs of the established vegetation under designed environmental conditions (for example, the 1 in 50 year drought). In many cases, it therefore appears that clays are ineffectual barrier systems, and the establishment of vegetation above the clay would further undermine its efficiency as a barrier.

In all soil columns, the roots of the established grass/legume sward reached the underlying contaminated wastes. In the second experiment, the roots had reached a depth of 60 cm in 12 months. In the first experiment, the roots not only reached the wastes, but the established vegetation also contained elevated concentrations of the supposedly isolated metals, particularly zinc, a known phytotoxin.

In many cases, the plant roots increased in mass per unit volume either just above or just within the waste as compared to the adjacent materials. Contaminant uptake through root sorption is therefore likely to be greater than expected assuming the more normal gradual decrease in rooting density with depth.

There are many questions that need to be answered concerning the relationship between the conditions within the columns and within the polyethylene tunnel house as compared to conditions occurring at a reclaimed site. It is likely that the upward fluxes achieved in the soil columns were so high that they might never occur under the climatic conditions prevalent in the United Kingdom. There is also the possibility that rainwater would wash the migrated contaminants back down the soil profile. This effect would depend on the cation exchange capacity of the barrier or topsoil. Cation exchange derives from the negative charges on clay micelles and organic matter which provide a binding capacity for metals and other positive ions. The stability of these resulting complexes is, however, questionable.
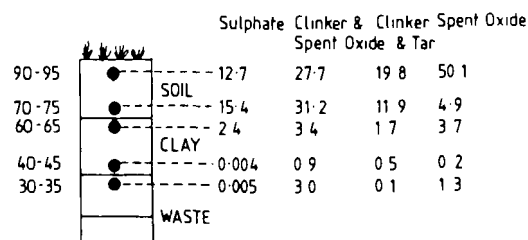
Figure 9
Root Densities within the Soil Columns (mg/g dry soil)

The columns provided a means of measuring the upward water and contaminant flux under the extreme conditions in a polyethylene tunnel house. Where vegetation growth was kept high, and the water table kept at the base of the column, upward fluxes would be extremely high. While information relating these conditions to those of reclaimed site needs to be collected, the constructed soil column remains a useful technique in assessing potential covering systems and the long term efficiency of remedial actions.

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SYNOPSIS OF 1983-1988 OUTLOOK OF ENVIRONMENTAL CONCERNS FROM SCIENTISTS AROUND THE WORLD*

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INTRODUCTION

This paper contains a summary of the remarks made by each participant in a panel discussion which the senior author chaired on September 23, 1983, at the 4th International Conference for Environmental Participation at Paul Sabatier U., Towlance, France.

The comments made by each speaker were personal in nature and not officially those of his or her particular country, university or government agency.

The following is a short synopsis of each panel member's remarks.

Dr. El Gohari, Egypt, National Research Center, Cairo, Egypt

Dr. Gohari was concerned that there are definite limitations in the design and operation of wastewater treatment plants regarding the destruction of toxic compounds and viruses. Research and development should be focused toward:
•Recycling waste water to reduce overall water withdrawal
•Use of less harmful chemicals
•Increased use of physical/chemical treatment instead of biological treatment.

Dr. Robert Martin, University of Birmingham, Birmingham, England

Dr. Martin stated that since the middle 1970s, the world has witnessed an energy crisis, industrial recession and increasing sophistication of analytical instrumentation. Meanwhile, standards are being formulated based on measurements made to ever higher orders of magnitude. With these standards, pressure groups exert untold influence and induce hysteria and fear in the uninformed. A proper perspective must be maintained so that instruments are controlled, and are not the controlling factor, so that decisions regarding environmental standards are logical, economical and technically feasible.

Dr. B.A. Bolto Csito (Australia)

Dr. Bolto stated that there was a need for new water and wastewater treatment processes. In developed countries, lower capital costs would characterize these new processes; in developing countries, the emphasis would be on appropriate technology. Greater attention should be given to the recycling of products from wastewaters and to the removal of heavy metals from wastewater sludges. The significance of water supply for agriculture in Australia meant that methods of removal of salts and turbidity should be explored.

Dr. A. Hamza (Egypt), Institute of Public Health

Dr. Hamza pointed out that the monitoring of wastes was a major concern worldwide and that, in the future, there should be more attention paid to the monitoring of industrial and domestic wastewater treatment processes. Industry from developed countries was welcome in Egypt, but overseas aid, employment and commercial growth should not obscure responsibility for the impact of hazardous wastes on the environment.

Dr. R. Ben Aim (France), University Paul Sabatier

Dr. Ben Aim's opinion was that wastewater treatment commonly involved the treatment of dilute aqueous systems. Research should consider the behavior of micropollutants in dilute systems. The increasing use of physical/chemical processes in wastewater treatment and the increasing use of biological processes in water treatment have resulted in an increasing similarity in both water and wastewater treatment. Greater emphasis on the optimization of treatment plant operation should be a priority.

Dr. L. Pawlowski (Poland), Loblin Marie Curie S Kowdowski U.

Dr. Pawlowski stated that treatment processes should become cheaper and more efficient. To meet these objectives, it would be necessary to acquire a greater understanding of the mechanisms by which these treatment processes removed particular pollutants. This understanding could only result from greater chemical knowledge of the processes, the pollutants and their inter-relationships.

Dr. G.N. Pandey (India), National Environmental Engineering Research Institute

Dr. Pandey told the group that numerous research objectives were necessary in India. The significance of agriculture was stressed. Research should investigate the environmental impact of pesticides and fertilizers; a balance between energy use and environmental degradation should be sought in the production of food. Industrial waste treatment, corrosion research, the development of low energy technology and the need to improve communication between environmental scientists and the medical profession to better understand the effects of organic pollutants on human systems were all important.

Dr. L.H. Wang (Taiwan), Taichung U.

Dr. Wang highlighted areas of concern in Taiwan. The extremely high population density means that waste disposal is of major importance; disposal of solid wastes is hindered by a shortage of

land. Air pollution problems have been encountered; the presence of highly toxic dioxin has been observed. Nuclear energy plants have discharged nuclear wastes into seawater; research should consider the polluting effects of such wastes on seawater and its ecology.

Dr. L. Liberti (Italy), Bari

Dr. Liberti reported on two-on-going research projects in Italy. One project involves the study of the interception of wastes from towns on the Adriatic coast; ammoniacal nitrogen and phosphates present in effluents are being converted to ammonium phosphate fertilizers. The potential benefits of this project are two-fold: fertilizer production and cleanup of the Adriatic Sea. In the second project, scientists are studying the reuse of wastewater for agriculture; large ponds are used to collect and store effluents. Sunlight has been observed to inactivate viruses.

Dr. U. Zoller (Israel)

Dr. Zoller felt that the essential issue was not what could be done in future years; it was what should be done now. Decisions on what should be done depend on economy and various social constraints. The future should see greater emphasis on environmental education and ultimate disposal of pollutants; inadequate information is presently available on the final effects of pollutants on the world ecosystem.

Dr. V. Soldatov (USSR), Minsk

USSR Academician Soldatov welcomed the conference and noted that it had become a tradition for environmental scientists throughout the world, since the conference's beginning in the mid-1970s, to focus on only one aspect of technology (i.e., ion exchange) and then examine all the ramifications to the solution of environmental problems.

Dr. Zimny Poland stated that the emission of oxides of nitrogen and sulphur had significantly increased in the last 30 years. Research was necessary to investigate the effects of such air pollution on soil and the plants and animals living in and on that soil.

Mr. L. Roland (UK), Foster-Wheeler, Reading, Berks, G.B.

Mr. Roland reminded the assembled delegates that he, as a representative of industry, was in a minority being surrounded by academic researchers. The economic facts of life in industry meant that future research and development should be conducted with economic realism and without courting hysteria from pressure groups and the media.

Additional Comments

Additional comments by other delegates present at the discussion session included remarks by Prof. A.L. Kowal (Poland), who wanted to see more research on the utilization of wastewater; reuse of water and recovery of products would be an investment for the future. Dr. A. Trier (Chile) pointed out the need for air pollution standards in developing countries. Various unidentified speakers from other countries including Thailand, Japan, Cuba and Canada streesed the need for the use of non-toxic products in agricultural applications, the need for research on methods to clean up marine and estuarine environment, the significance of acid precipitation arising from air pollution, the importance of international cooperation in the fight against environmental pollution and the need for effective low cost solutions to air, water and solid waste problems.

CONCLUSIONS

The authors feel that developing nations, not having hard currency, need environmental pollution control techniques based on indigenous resources. Their environmental goals should be indexed to their development vis-a-vis the industrialized nations. For example, if one plots the U.S. environmental protection criteria against its industrialization or economic development since the turn of the century, one finds the increasing level of environmental standards directly proportional to the rise in economic development and industrialization.

OVERVIEW OF HAZARDOUS WASTE SITE PROBLEMS IN WALES

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INTRODUCTION

Wales is a small country which, with Scotland, Northern Ireland and England, forms the United Kingdom. It has a population of just under 3 million people and a land area of 8,018 square miles. Although politically united to England for nearly 450 years with the two countries sharing common systems of law and government, Wales has a history, culture and language of its own. Although English predominates, Welsh, a Celtic language, is thriving.

The Welsh Office which is responsible for functions in many fields such as agriculture, education and environmental control has substantial administrative autonomy. Within the Welsh Office headquarters in Cardiff, the Water and Environmental Protection Division advises on a range of matters including hazardous waste sites. This Division has a research program which is designed to identify, alleviate and possibly provide solutions to environmental problems in Wales.

DEFINITION OF CONTAMINATION

"Contaminated land" is the term used in the United Kingdom to describe land that contains toxic substances in such concentrations that they present a potential threat directly or indirectly to man, to the environment or to such other targets as building structures. A distinction is made between contaminated land and derelict land, which has been defined as land which is so damaged by industrial development that it is incapable of beneficial use without treatment. Examples of the latter category are disused quarries and former railway land; land dereliction from natural causes is not covered by the definition. Much, but not all, derelict land is contaminated; some sites, although contaminated, are in beneficial use and are therefore not derelict.

Land can be contaminated in a number of ways, e.g., by atmospheric fallout, by flooding or seepage of liquids, or by deposition or spreading of solid contaminants. However, the concentrations of toxic substances so produced are in most cases not high enough to constitute an immediate danger; in Wales, the term contaminated land is considered to embrace land which has been contaminated by metalliferous mine wastes, industrial usage or waste disposal.

Although not containing toxic substances, a type of derelict land which presents a potential hazard to man and other targets is land upon which colliery waste and slate waste have been dumped in such a way that the land constitutes a danger to those living nearby. This type of derelict land has a particular significance for Wales because of the disaster which occurred in 1966 when colliery waste, made unstable by heavy rain, avalanched down the mountain to engulf Pantglas School in the village of Aberfan. One hundred and forty-four people, including 116 children, died within a few minutes. This tragedy, more than anything else, dramatically underlined the dangers of spoiling land. Since 1966, a determined drive has been underway in Wales to clear hazardous sites and to remove unsightly waste so that land can be restored to productive and beneficial use.

HISTORICAL BACKGROUND

Metals were mined in Wales before the Roman occupation, and the Roman conquest of the Principality was possibly caused by the need of the Romans for Welsh lead and gold. Even as early as the 18th century it was said that lead mines "enrich a person or two in an age and entail poverty on hundreds for generations to come. The waters from the mines spread sterility over the adjacent fields and kill all the fish in the rivers." Mining reached its peak in Wales in the period from 1845-1938, but has now virtually ceased except for speculative attempts to remove metals from mine wastes on a commercial basis. However, mines being worked at the time of the Romans are still giving cause for concern today because they constitute a possible threat to health and are a cause of poor fish survival in some Welsh waters.

The industrial revolution also left Wales with a legacy of contaminated land. At a time when people were struggling to make a living, it is understandable that consideration for the environment took second place. Although much has been done to make good the damage caused by earlier generations, Wales still shows the scars of the industrial revolution. A notable example is the Lower Swansea Valley which was the most important non-ferrous smelting center in the world during the 18th century. Refining of copper, lead, silver and zinc left the Valley with wastes from 250 years of working, but reclamation in progress from 1966 has done much to restore the area.

Wales also was used as a dumping ground for toxic chemicals for many years before the disposal of wastes was controlled: therefore, there are a number of sites, such as former quarries, containing drums of unknown chemicals which are a permanent threat to the surrounding area. Such sites present complex problems making it almost impossible to devise a satisfactory method of redevelopment within a reasonable cost.

While despoliation of the land was ignored, and understandably so, by past generations, there is a new environmental consciousness in Wales today. The words Lower Swansea Valley, an area in South Wales, are virtually synonymous with industrial devastation—such places, tolerated in the past, are no longer acceptable.

RECLAMATION

Within a month of the Aberfan disaster, a special unit was set up in the Welsh Office to lead, encourage and coordinate a program of reclamation. A determined effort has been made to clear away dangerous dereliction and to restore land to productive and beneficial use. Since many land reclamation projects are designed to create land for new industry, the functions of reclamation were transferred to a separate body, the Welsh Development Agency, which came into operation on Jan. 1, 1976. The Agency has power to meet the whole cost of reclamation schemes promoted by County and District Councils in cooperation with other public bodies such as the National Coal Board, Forestry Commission and the Countryside Commission.

In its first three years of operation, the Agency approved projects for the reclamation of 6,000 acres of land at a cost of more than 43 ($55 US) million. To come more up to date, the Welsh Development Agency announced a £35 ($45 US) million rolling program in August 1984 as a determined attack on the worst problems remaining in Wales. The program, to be completed progressively over the next 5 years, gives top priority to schemes necessary to eliminate hazard to life and property. Reclamation releasing land for economic development receives the next priority and the program includes many such schemes.

RESEARCH

With large areas of Wales bearing the scars of centuries of mining, quarrying, smelting and other past industrial activities, mounds of coal and slate waste, toxic heaps of mine spoil, quarries containing highly toxic chemicals and the decaying remains of industrial processes can have a marked effect upon the lives of people living nearby. The Welsh Office has a research budget with funds available for study of these problems to clearly identify their extent and nature and to develop methods of reducing if not removing the hazards. A brief description of some of the research which has been conducted or is being conducted now on the problems posed by hazardous waste sites follows.

Halkyn Mountain Project

Mines in the Halkyn Mountain area of North East Wales were worked at the time of the Romans. Their operation left contaminants, and this research project arose because of the public concern about possible health hazards presented by the high level of metals in local soils. Starting in 1975, a study was carried out to ascertain the relationship between blood lead levels of the local population and the lead content of soil, dust, locally grown vegetables, air and water.

As expected, the concentrations of heavy metals in the soils were found to be high, particularly when compared with concentrations in a collection of soils from another part of Wales with no known contamination (Table 1). Settled house dusts and garden soil samples were taken at houses where blood samples were taken: metal concentrations were found to be high in the soil and the dust (Table 2).

Although no simple figures can be given for acceptable concentrations of metals in soil and dust, it is interesting to note that it is generally accepted that only concentrations for lead in soil below 500 μg/g can be considered as uncontaminated for the development of the land for garden purposes in the UK. Some think the same figure to be the safety limit for lead in dust.

In view of the public interest in the UK in lead, the study concentrated on this metal. Therefore, blood samples were taken from young children and adult women to determine the extent to which lead from the soil was getting into the bodies of residents in the area (Table 3).

The blood lead levels were found to be 30 to 50% higher than for women and children in other parts of Wales.

Although these levels were high enough to constitute an immediate threat to the health of the local residents, it was felt that the study should try to discover how lead was getting into the bodies of the residents.

Table 1
Summary Values for Total Metals in 260 Soil Samples from Halkyn Mountain with Values from West Wales for Comparison

Metal Concentration
(ug/g dry soil)

Halkyn	Pb	Zn	Cu	Cd
Mean	886	728	18	6.1
Minimum	35	10	2.3	0.4
Maximum	47,995	49,393	252	540
West Wales				
Maximum	70	195	29	2.4

Table 2
Summary Data for 59 Paired Samples of Garden Soils (S) and Dust (D) from the Halkyn Area

Metal Concentration
(ug/g dry matter)

	Pb		Zn		Cu		Cd	
	S	D	S	D	S	D	S	D
Mean	1779	480	1143	1166	24	200	62	0.8
Median	1474	346	827	937	19	159	4.2	0.7
Minimum	33	8.4	46	122	5.4	15	0.1	0.1
Maximum	9631	2943	4383	5239	91	893	27	3.6

Table 3
Mean Blood Levels (in μg/100 ml) in Halkyn and a Control Village. (A Correction Is Made for Capillary Results in Children.)

	Observed Mean Blood Level	Corrected Mean Blood Level	Proportion Over 20 μg/100ml	30μg/100ml
Halkyn				
Adult Women	12.8	---	5.5%	0.0%
Mothers	11.8	---	4.5%	0.0%
Children	22.6	14.3	15.9%	0.3%
Control Village				
Mothers	7.9	---	0.0%	0.0%
Children	17.6	11.2	5.5%	0.0%

As a result, lead in air and the water supply was determined; the concentrations were so low that they were thought to make only minor contributions to body intake. An assessment was also made of the levels in the dust on childrens' hands, on kitchen surfaces using the wet wipe technique and in locally grown vegetables. A correlation was found between the amount of lead on childrens' hands and their body lead; there was also evidence that lead could be getting into the food chain through dust on kitchen surfaces. The

eating of locally grown vegetables was also associated with raised blood lead levels. Lettuce, carrot, beetroot and radish were found to absorb more lead than the other species examined, whereas lettuce, carrot, swede and cabbage took up more cadmium. Potatoes, peas, beans and cauliflowers were found to be poor absorbers of both metals.

Advice was therefore given to residents to avoid high intake of locally grown vegetables such as lettuce and carrots, to keep working surfaces in the home extra clean, to encourage children not to suck their fingers and articles such as toys and to wash home grown produce carefully before consumption.

Background Heavy Metal Survey for Wales

To say that land and other environmental media are contaminated, it is necessary to show that the concentrations of contaminants contained in them are higher than normal. It is difficult to define what is meant by normal, and little data are available to provide a baseline for comparison. The lack of data became quite apparent during the Halkyn Mountain study.

Consequently, the University College of Aberystwyth was asked to determine the concentration of heavy metals in Welsh environmental media so that a baseline could be established for future comparison. The program of work started in 1983 involves the analysis of soils, dusts, grass, cereals and vegetables for arsenic, cadmium, copper, mercury, lead and zinc. The results of the analysis of the first of the 1,640 soil samples taken for the survey are shown in Table 4. It is intended that maps showing the heavy metal distribution in the soil of Wales will eventually be produced from this work.

Survey of Contaminated Land

Although it may be thought that the locations of contaminated areas in a small country like Wales would be well known, this is only true of the more obvious sites since no comprehensive surveys have ever been conducted in the UK. Derelict land surveys undertaken by local authorities and coordinated by central government have only provided estimates of the amount of contaminated land in Wales. Large areas of central Wales are sparsely populated and yet, in contrast, the south is congested.

Land is in short supply, particularly in the coal mining valleys where only a very small amount of it is suitable for development because it is too steep. This shortage of land brings pressure to develop any unused sites, and land near or in towns is at a premium in Wales. Failure to discover before redevelopment that a site is contaminated can be costly both in terms of financial resources and in relation to the risks to which the developers and the eventual occupants of the site are exposed. Therefore, a need was felt for a survey which would locate contaminated sites and which would classify them according to their potential hazard, the need for remedial treatment and the factors which were likely to inhibit redevelopment.

Table 4
Summary Statistics for Metals Concentration in Welsh Soil Samples
(Metal Concentrations µg/g dry soil)

	Metal Concentration					
	Pb	Zn	Cu	Cd	Co	Ni
Minimum	3.4	5.5	<0.5	<0.3	<0.2	<0.9
Maximum	3369	2119	215	15	190	169
Mean	93	81	19	0.6	9.3	19
Median	39	62	13	0.3	8.2	14
N	225	225	225	225	225	225
St.Deviation	276.8	148.5	26.3	1.18	13.3	18.2

Table 5
Structure of Site Contamination Records

Field No	Name	DMS name	Description
1	Code number	COD	Unique identifier
2	Grid reference	GR	Map reference
3	Grid sequence	GSQ	1km² location
4	Type	TYP	Site use
5	Name	NAM	Site name or owner
6	Location	LOC	County, district & nearest town
7	Topography	TO1	Description of site structure
8	"	TO2	
9	"	TO3	
10	Contaminants	CON	Most likely contaminants
11	Period of use	TIM	Period of contaminating use
12	Site area	ARE	Site area in hectares
13	Contaminant Scale	CSC	Amount of contaminated material
14	" toxicity	CTX	Toxicity of contaminants
15	Proximity to housing	PRO	Distance to housing (km)
16	Status	ST1	Current condition of site
17	"	ST2	
18	"	ST3	
19	Hazard factor	HF	Scale of hazard
20	Development factor	DF	Scale of priority for attention
21	Confidence	CNF	Probability of contamination
22	Comments	CO1	Additional information
23	"	CO2	
24	"	CO3	
25	Last update	UPD	Date of latest check on data
26	Source	SOU	Primary source for site identification

A survey of Wales was conducted in 1983/84 by Liverpool University and funded equally by the Welsh Office and the Welsh Development Agency. A methodology was developed using various information sources such as maps, aerial photographs, local knowledge, etc., to locate sites which were then classified as described above.

The survey, the first in the United Kingdom, took one man-year to complete and identified over 700 sites covering a total area of 3,787 hectares of land which are believed to be contaminated. No soil surveys were attempted because of the large number of sites involved, but it is apparent that such surveys are needed to fully assess the potential problem in the event of development.

A deliberate decision was taken not to record sites which were in beneficial use, housing for example, because it was felt that to include them in the survey might create needless concern.

In addition, sites with areas less than 0.5 ha were usually excluded. To do otherwise would have led to a street by street survey which would have been bogged down with an investigation of possible sites which had little or no development potential. Nevertheless, where acutely contaminated sites such as gas works and tar lagoons smaller than 0.5 ha were identified, they were recorded because of their significance.

Wales now has a comprehensive record of sites over the whole of the country which are thought likely to be contaminated. The information about each site is divided into 26 fields (Table 5) and has been entered in a computer database so that site records can be picked out by means of the reference number or name of the site. More importantly, the computer has been programed to give, on

request, all records of sites with a particular contaminant, in a particular area, with pre-specified hazard or development factors or combinations of both. A typical computer record for one site is reproduced (Table 6).

The records of this survey can be viewed as a national register which can be used to forewarn potential developers of the possibility of meeting problems and therefore avoiding unplanned costs, accidents and health hazards during and after redevelopment. The question of a national register, which could be consulted as a standard practice in land conveyancing transactions, is under consideration but has not yet been fully discussed within Welsh Office because the results of the survey have only recently become available.

Effectiveness of Land Reclamation Schemes

Although much progress has been made since 1966 to reclaim contaminated land in Wales, very little information is available to assess the cost-effectiveness and life expectancy of reclamation systems. Liverpool University has been asked by the Welsh Office to develop models which can be used to assess the effectiveness of land reclamation systems.

Initially, an assessment is being made of existing models to determine which model or models can be developed to predict the optimum reclamation system, the life expectancy of such a system, the cost versus life expectancy options available and the consequences to the environment of the breakdown of a reclamation system. The developed model or models will be used to predict the optimum reclamation system for sites in Wales for which monitoring data are already available. No results are available as the project only started in April, 1984.

Mineral Fibres from Slate Waste

Slate has been worked from the hills in some parts of North Wales for centuries. The middle of the last century was a boomtime in Britain for the building industry, and the demand for slate was at its peak. In less than 100 years, thousands of tons of slate were

Table 6
Example of Computer Print-Out of Site Contamination Records

```
DMS current record.        File = CONTAMINATED LAND IN WALES....   Page

COD............   12052  GR..............  SJ245739
GBQ............   SJ2473
TYP............   CHEMICAL WASTE
NAM............             BURNING TIP
LOC............
CLWYD: DELYN: FLINT
TO1............
LARGE HEAPS ADJACENT TO TIDAL INLET FROM R.DEE
TO2............

TO3............

CON............
SULPHIDES: VOLATILE ORGANICS
TIM............   1890-1980          ARE............   1.5
CSC............
CTX............   HIGH   PRO............   0.4
BTI............
DISUSED: PARTLY VEGETATED: SOME AREAS BURNING UNDERGROUND
BT2............

BT3............

HF.............   4  OF............   3  CNF............   ***
CO1............
LARGE AMOUNTS OF WASTE RAYON: PARTLY COMBUSTED.
CO2............

CO3............

UPD............   SEP 1983
SOU............   L.A.
```

quarried out of the mountainside, split, cut and exported for roofing. In most places today the quarries are silent, but there are many reminders of slate's golden age. The huge quarries and the vast spoil heaps still tower over the slate villages and dwarf all around them.

Apart from being an eyesore, this waste constitutes a potential danger to people living nearby as its stability must always be in question. In view of this danger, it was thought that if a use could be found for the slate debris, it would encourage its removal. Consequently, the Welsh Office has funded a project to investigate the use of slate as a raw material to make fiberglass.

Fibers have been produced from slate both by drawing to produce continuous fibers and by blowing to form mineral wools. The preferred process involves melting the slate and appropriate fluxes in a platinum crucible at very high temperatures. Commercial applications are now being considered for the fibers, and interest has been expressed by industrial firms in their use as a possible replacement for asbestos in some products.

CONCLUSIONS

The last meeting of the NATO/CCMS Pilot Study Group on Contaminated Land was held in Cardiff in April, 1984. The Welsh Office was very pleased to host this meeting because contaminated land presents a serious challenge to the Principality. Wales, with its legacy of hazardous waste sites, provides a microcosm of the problems encountered in many parts of industrial Europe. Any initiatives which would improve the chances of redevelopment of contamainated sites are most welcome to the people of Wales.

Wales is a green and beautiful land with mountains, lakes and beaches second to none, but 200 years of industrialization have left many grim reminders of the past. In less than two decades, the worst of the accumulated devastation has been tackled by the research and positive action which followed the horror of Aberfan.

However as old problems are solved, new ones arise—recently, for example, there was concern when the erosion of a crude covering layer exposed waste asbestos on a former industrial site near a housing estate. In another case, the excavation of a site for industrial redevelopment revealed gross soil contamination by PCBs resulting from the disposal and deterioration of capacitors. It seems, therefore, that much remains to be done before the debt to the land has been fully repaid.

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TREATMENT AND DISPOSAL OF HAZARDOUS WASTEWATER FROM FOUNDRY CYANIDE HEAT TREATMENT OF DELTA STEEL COMPANY LIMITED

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INTRODUCTION

In the early 1950s and 1960s, the greatest pollution problem in the steel industry was the amount of fumes and dust emitted to the atmosphere.[1] Today, the emphasis is switching to the problems caused by solid and hazardous waste and the control of discharges of liquid effluents.

The Delta Steel Company began to use cyanides in a new heat treatment process in the foundry department where the steel had to be quenched with oil and rinsed with water.

Cyanides, which are extremely toxic, especially at low pH, result from the scrubbing of steel plant gases, from metal cleaning and electroplating processes and from certain chemical industries. Small doses (2.0 to 4.7 mg CN/day) are normally not lethal to adult humans as the liver is capable of detoxifying the chemical. However, death will occur as the result of large doses when the detoxification processes of the liver are overwhelmed.

Many lower animals and fish seem to be able to convert cyanide to cyanate which does not inhibit respiratory enzyme activity. However, not all fish are immune. Studies have shown that concentrations of 1 mg/l will kill certain pollution-sensitive fish in 20 min, and compounds formed by the reaction of cyanide with heavy metals may be even more toxic than cyanide alone. It is for this reason that the control of cyanides in industrial effluents is extremely important.

CYANIDE DESTRUCTION

This process was entirely new to the investigators since the steel plant was still in its infancy. Hence, in their preliminary investigation, the authors had several constraints. In spite of this, the investigators have perfected a method for the treatment and disposal of the plant's cyanide-bearing wastewater. In this paper, the authors present the results of their preliminary investigation of the process employed by the Delta Steel Company to remove cyanide from their contaminated rinse waters.

The alkaline chlorine oxidation method, which is the most widely applied process for the destruction of cyanide, was used.

Oxidation of cyanide occurs by two separate chemical reactions. In the first stage, cyanide is oxidized to carbon dioxide and nitrogen; this reactionis pH dependent. In the second stage, cyanide is oxidized to cyanate (CNO^-); at pH 9.0, the reaction will go into completion in 3 min. The reactions are as follows:

$$Cl_2 + 2OH^- \rightleftharpoons OCl^- + Cl^- + HOH \qquad (1)$$

$$CN^- + OCl^- \rightleftharpoons CNO^- + Cl^- \qquad (2)$$

$$CNO^- + 1.5\,OCl^- + 0.5\,HOH \rightarrow 0.5 N_2$$
$$+ HCO_3^- + 1.5 Cl \qquad (3)$$
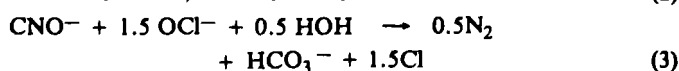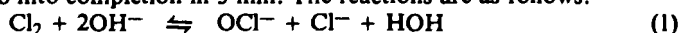
The samples for the laboratory tests were prepared by dissolving a known amount of reagent in water to correspond to values in Table 1. Various dilutions were made and treated with calcium hypochlorite (65% purity) and caustic soda. The authors used 2kg of calcium hypochlorite/kg cyanide which is about 1.2 times the stoichiometric amount required to convert the total cyanide into nitrogen and carbon dioxide.

After alkaline chlorination treatment according to pH levels shown in Table 1, potassium iodide starch paper was used for the detection of available chlorine. Then, the resulting precipitate was removed via filtration. The amount of residual cyanide in the filtrate was then determined by the pyridine-pyrozolone method as outlined by the USEPA in *Methods for the Chemical Examination of Water and Wastewater*.[3]

Experimental Procedure

Titration using silver nitrate is used to measure concentrations of cyanide exceeding 1 mg/l. This analytical procedure uses a standard solution of silver nitrate to titrate cyanide in the presence of a silver sensitive indicator:

- Pipette 100 ml of sample into a 300 ml Erlenmeyer flask
- Add 6 ml of 10% NH_4OH solution and 0.2 g KI
- Titrate with 0.1 N Ag NO_3 solution until turbidity appears as the end-point
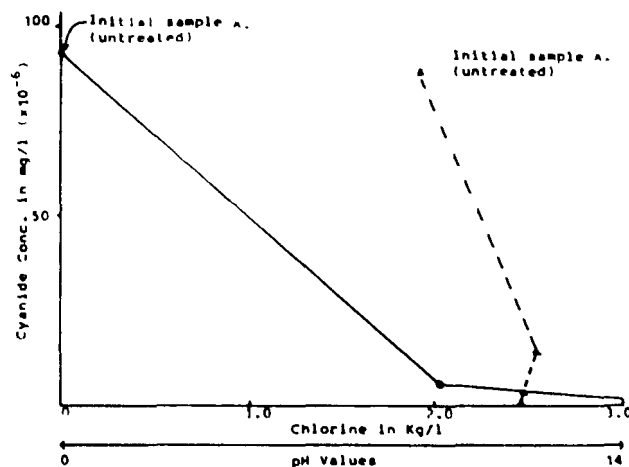
Figure 1
Cyanide Concentration Reduction as Progressively Larger Amounts of Calcium Hypochlorite Are Added

Table 1
Cyanide Treatment

Sample Type	Concentration (mgl)	pH
Rinse Water	91.05	7.8
Cyanide/oil extracted mixture	15.61	5.7
First Treatment:		
a. Rinse water	7.8	12.50
b. Cyanide/oil mixture	---	---
Second Treatment:		
a. Rinse water	2.01	12.20
b. Cyanide/oil mixture	---	---
Final Analysis:		
a. Rinse water	1.0	12.00

The presence of turbidity requires correction with a known KCN solution to determine the blank value; to do this, prepare a 50 mg/l KCN solution, take 10 ml of titrant, calculate the blank correction and subtract the calculated blank value from the known sample value.

Treatment

For effective treatment, eight parts of chlorine should be used with one part of cyanide (Table 1).

CONCLUSIONS

The reaction progressed rapidly in the treatment phase. From the graphical representation (Fig. 1), one can see the sharp decrease in the cyanide concentration after the first 2 kg of calcium hypochlorite were added.

The rapid decrease in the cyanide concentration, as shown in Figure 1, gives a true picture of the treatment effectiveness.

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PURIFICATION AND RECYCLING OF GROUNDWATER CONTAMINATED WITH PETROLEUM PRODUCTS AND CYANIDES—THE KARLSRUHE (FEDERAL REPUBLIC OF GERMANY) DRINKING WATER TREATMENT PLANT

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INTRODUCTION

The Durlacher Wald water treatment plant in Karlsruhe, Federal Republic of Germany, is located next to a major railroad marshalling yard through which considerable quantities of petroleum and petrochemical products have been transported for years. During transfer of these products, many spills have been experienced, and these have resulted in pervasive contamination of some of the Durlacher Wald plant groundwater wells.

On the other side of the plant is an abandoned chemical dump which, although closed down in the early 1900s, had begun leaching cyanides into two of the Durlacher Wald groundwater wells.

By the late 1970s, two of the plant's four water supply wells had been closed down because of chemical contamination, and the other two wells were being threatened. However, instead of closing down this plant, moving to a new site and building a new treatment plant, the city opted to install a new and unique groundwater treatment process, the technical basis for which had been demonstrated in laboratory studies but which had not been proven at full-scale operational water treatment plants.

The key to the new process involves the use of ozone to partially oxidize the biorefractory organic pollutants, rendering them biodegradable. Contaminated water is ozonized, then reinjected into the groundwater stream where it is purified by the natural biochemical action of groundwater microorganisms. The process, which was installed in 1980, has rejuvenated the contaminated groundwater supply, allowing the Durlacher Wald plant to reopen its closed wells and to continue producing high quality drinking water.

A detailed report of this success story was published by Nagel, et al.[1] in a German language journal. Because of the unique nature of this treatment process, its potential applicability to a broad range of similarly contaminated groundwaters and the fact that the process has not been described in the English literature, the present author will review this publication, adding a discussion of the technical principles which are the basis for the treatment process.

THE GROUNDWATER CONTAMINATION PROBLEM AT KARLSRUHE

The oldest of several water treatment plants supplying the city of Karlsruhe, Durlacher Wald is located next to the rail marshalling yard and has pumped water from four wells (each 32.70 m deep) since the turn of the century. Average daily water production is 33,600 m³/day (8.8 mgd). Groundwater normally is pumped to the surface, oxygenated to raise dissolved oxygen (DO) levels and sent to the Karlsruhe distribution system. In recent years, however, well #1, closest to the rail yard, had become contaminated with petroleum products and was closed down in 1978. The second

closest well to the rail yard (well #2) also was becoming contaminated and was close to being shut down.

At the other end of the well field, the number four well, next to a woods, had become contaminated with complexed cyanide from a chemical plant dump which had been abandoned in 1906; at the same time, well #3 also was showing traces of cyanides. The relationship of the well field to its contaminating sources is shown in Figure 1.
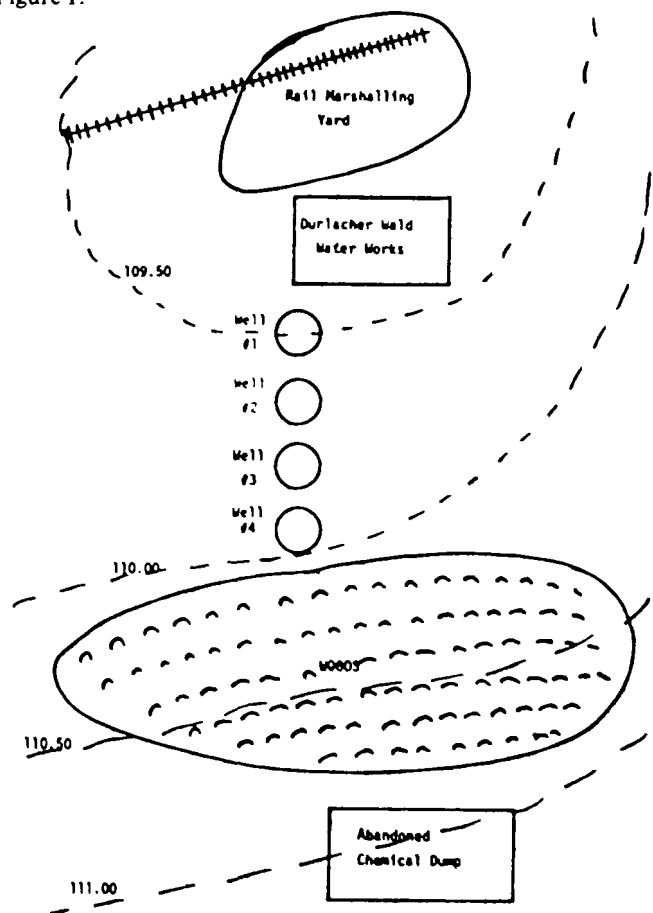
Figure 1
Durlacher Wald Water Works—Relationships of Contaminating Sources to the Groundwater Wells

Contamination of the well closest to the rail marshalling yard was indicated by a sharp increase in organics levels (to > 5 mg/l DOC), an increase in turbidity, a drop in DO concentration (to < 1 mg/l) and an increase in the iron and manganese levels (to 0.07 and 0.04 mg/l, respectively). The water quality in well #2, located 150 m downstream of the first well, began to decrease in the same manner during the first few months after well #1 was shut down.

At the same time, well #4 was becoming contaminated with the hexacyanoferrate complex "Berlin blue". Concentrations had risen above the maximum contaminant level of 0.05 mg/l, sometimes to as high as 0.10 mg/l. Consequently, well #4 also had been shut down.

Earlier studies of the groundwater hydrology at this plant showed that the wells are fed by groundwaters flowing into the wellfield from the direction of the rail yard and also from the woods at the other end of the field. At the average daily removal rate per well of 400 m3/hr (33,600 m³/day total water removal from the well field), the flow of groundwater between wells #1 and #2 is about 0.06 m/day. From these data, the normal flow time between the two wells is approximately 8 months.

THE CORRECTIVE WATER TREATMENT PROCESS

Technical Basis

Ozone has been used as a water treatment oxidant and disinfectant since the early 1900s. Although it was employed initially as a disinfectant in the later stages of water processing, ozone today is used more often to oxidize contaminants in the early stages of drinking water treatment.[2]

Even though ozone is the strongest oxidizing agent available for water treatment, it is rare that all carbonaceous materials present can be oxidized completely to CO_2 and water, even under prolonged ozonation conditions. On the other hand, ozone is quite capable of partially oxidizing organic materials, cleaving double bonds to produce aldehydes, ketones, alcohols and carboxylic acids. Aromatic rings can be ruptured by ozone, producing C_2-C_4 aliphatic oxidation products. High molecular weight organic compounds can be cleaved oxidatively to produce lower molecular weight materials.

All of these oxidized materials contain higher levels of oxygen-containing moieties and thus have higher degrees of polarity. This means that many relatively non-polar, biorefractory organic contaminants (such as petroleum-based hydrocarbons) can be rendered biodegradable upon partial oxidation with ozone. Several authors[3, 4, 5] have confirmed this benefit of ozonation, i.e., of converting biorefractory organics into biodegradable organics.

Ozone normally is generated from dried air in concentrations of 1% to 3% by weight; thus when water is ozonized, it is also aerated quite efficiently. As a result, the dissolved oxygen contents of ozone-treated waters will be increased simultaneously during ozonation.

Additionally, ozone readily oxidizes soluble iron and manganese ions to higher valent cations (Fe^{+3} and Mn^{+4}) which hydrolyze rapidly to produce insoluble materials [$Fe(OH)_3$ and MnO_2, respectively], which are readily removed from the ozonized water by filtration.

Finally, ozone will oxidize free cyanide and many complexed cyanides to the less toxic cyanate ion, which further degrades to CO_2, nitrogen and/or nitrate.

Hydraulic Flows

The new Durlacher Wald treatment process consists of ozoning water withdrawn from the contaminated and previously shut down supply well #1, splitting the volume of ozonized water into five equal fractions, then reinjecting these fractions into each of five infiltration wells. Three of these infiltration wells are placed strategically between supply well #1 and the rail yard; each is about 75 m from supply well #1, and each is laterally located 50 m from each neighboring well. These three infiltration wells form a partial groundwater intrusion boundary zone between the contaminating
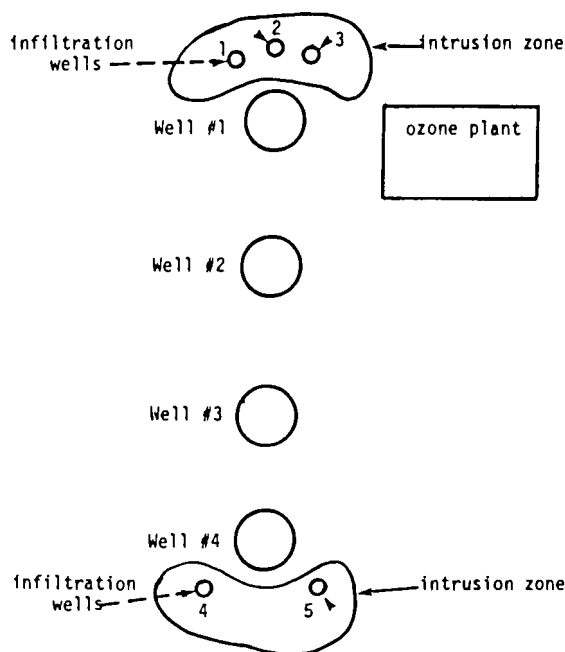
Figure 2
Durlacher Wald Water Works—Positioning of the Five Infiltration Wells

railyard and the supply well field, through which contaminated groundwater coming from the rail yard now must pass. This barrier delays penetration of the contaminated groundwater into the well watershed and mixes it with ozonized water which contains high levels of DO and biodegradable organic materials.

Two other infiltration wells of the same type are positioned 75 m in front of supply well #4, 50 m from each other, forming a second intrusion zone between the supply well field and the contaminating abandoned chemical dump. The positioning of the five infiltration wells with respect to the four supply wells and their sources of contamination is shown in Figure 2.

Process Details

A schematic diagram of the ozonation/reinjection process installed at the Durlacher Wald water treatment plant is shown in Figure 3. Water from contaminated supply well #1 is withdrawn at the rate of 400 m³/hr and ozonized in the water treatment plant located on the surface at the rate of 1 mg/l O_3 per mg/l of DOC. This volume of ozonized water is split into five equal portions (80 m³/hr each) and pumped simultaneously into the five infiltration wells described earlier.

The ozone installation at Durlacher Wald is designed to produce 1.3 kg/hr of ozone from air; however normal plant operation is conducted at an ozone production rate of 500 g/hr. If necessary, ozone can be produced from commercial oxygen, increasing the ozone output to about 2.6 kg/hr. Total energy requirements for ozone production, including air preparation and controls, are between 18 and 20 Wh/g of ozone produced. The dissolved oxygen content of the water after ozonation has been increased to 9 mg/l.

This ozone treatment process was installed at the Durlacher Wald plant in May of 1980 and began operating in June, 1980.

EFFECTIVENESS OF THE NEW WATER TREATMENT PROCESS

During the initial period of operation, June 1980 through August 1980, 450 m³/hr of water was pumped out of supply well #1, ozonized and distributed equally (150 m³/hr) to the three infiltration wells ahead of supply well #1. The rate of groundwater flow under these conditions is approximately 6 m/day, which means that
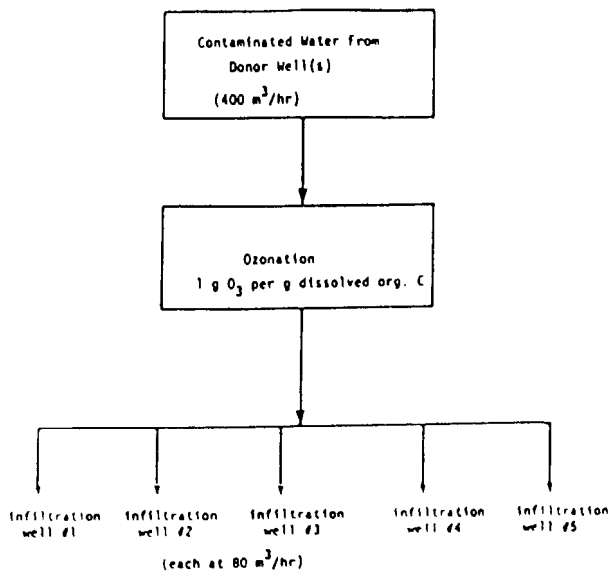
Figure 3
Schematic Diagram of Ozonation Process at Durlacher Wald Water
Works for Treating Contaminated Groundwaters

approximately two weeks were required for the treated water to flow from the infiltration wells to supply well #1. DO levels in supply well #1 began to increase about mid-June from 1-2.5 mg/l and reached a maximum ($>$ 8 mg/l) in mid-July.

During October, 1980, the initial process was modified so that only 80 m³/hr of ozonized water was sent to each of the three infiltration wells near supply well #1 (240 m³/hr); the remaining 200-240 m³/hr of the ozonized water was sent to the two infiltration wells in advance of supply well #4. The decrease in the volume of water sent to the three infiltration wells ahead of supply well #1 resulted in reducing the groundwater flow velocity, thereby lengthening the residence time of the infiltrated water in the ground to approximately 22 days. This resulted in a decrease of DO levels in supply well #1 to approximately 3 mg/l. Over the next five months of operation under this revised mode, the DO level in supply well #1 again rose. By the end of 1981, the DO levels in all four supply wells had reached an average level of 6-8 mg/l.

During the initial 10-week period of operation of the new process (June-August 1980), oxygen consumption in supply well #1 was approximately 40 kg/day; subsequently, however, the oxygen consumption became almost negligible. These data indicate that the initial high organic loading present in contaminated supply well #1 was being degraded microbially, under aerobic conditions, and that the carbonaceous, polluting materials were being converted into CO_2 and water. After the organic contaminants had been largely biodegraded, the oxygen consumption decreased to values more in line with those of relatively unpolluted waters.

The dramatic changes in DOC levels found in each of the four wells prior to and subsequent to installation of the ozone treatment process are shown in Figure 4. Levels of 3 to 5.5 mg/l in early May, 1980, in supply wells #1, #2 and #3 fell to about 1.5 mg/l by August 1980. By the end of 1981, the DOC levels of all four wells were only slightly above 1 mg/l.

Similar favorable data were obtained by analysis of specific organic constituents. Prior to installation of the ozonation process, petroleum hydrocarbons were found routinely in supply wells #1 and #2; currently, these types of organic compounds no longer can be detected. Additionally, concentrations of iron and manganese, which previously had reached levels of 0.07 and 0.04 mg/l, respectively, are again below the limits of detectability.

Finally, the levels of cyanide in supply well #4, which had risen to as high as 0.11 mg/l in early 1980 (and which was present in supply well #3 at levels of 0.01-0.02 mg/l), dropped to below the

German drinking water standard of 0.05 mg/l by July 1980, and by late 1981 was undetectable in both supply wells #3 and #4.

Bacteriological Considerations

Because ozone is a powerful disinfecting agent, it might appear that ozonation of contaminated groundwater could destroy microorganisms and thereby decrease microbiological activity in the groundwater. However, such is not the case when this treatment process is properly designed and operated. Although ozone will disinfect microorganisms in the 400 m³/hr of wellwater withdrawn, this water is reinjected into the flowing groundwater stream, which is replete with microbiological activity. The use of low ozone dosages (1 g O_3/g DOC), coupled with ozone's short half-life in water, assures that there will be no residual ozone present by the time the ozonized water is reinjected into the infiltration wells and comes in contact with fresh groundwater.

The ozonized, disinfected, reinjected water stream also contains high concentrations of dissolved oxygen in addition to partially oxidized organic materials which are more polar and more readily biodegradable than before ozonation. As a result of having more DO plus a biodegradable food supply, microbiological activity in the groundwaters flowing toward the supply wells from the infiltration wells actually increases as a result of the ozonation step.

Total cell counts (living and dead) in all four supply wells before the ozonation process was installed were between 2.5 and 3.9 x 10⁴/ml. One year later, the total cell counts had risen by a factor of about 10 (to between 1.5 and 2.0 x 10⁵ ml). On the other hand, the high colony counts in supply well #1 before the ozonation system was installed (140-280/ml) become lower by a factor of about 100 one year later. These currently low colony counts of supply well #1 are of the same order of magnitude as those of the other three supply wells.

Numerous bacteriological tests have confirmed that the pre-ozonation treatment has increased the biological activity in the ground significantly.[6,7] This increased bacteriological activity not only has improved the quality of the water, but also its bacteriological quality. Since the decrease in bacterial colony counts in supply well #1 was achieved (end of 1981), the city of Karlsruhe has been able to send waters withdrawn from supply wells #2, #3 and #4 directly to the city distribution system, without oxygenation, without additional chlorination and with no increase in colony counts being observed in the distribution system.
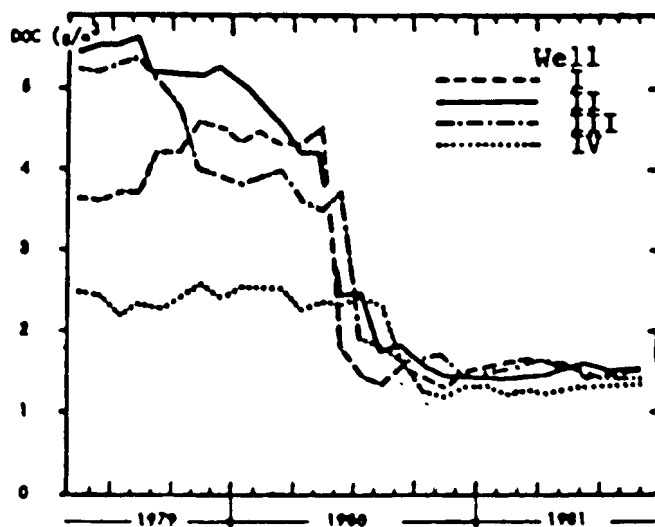
Figure 4
DOC Values (Sliding Mean Values) for the Operating Wells at the
Durlacher Wald Water Works, Before and After Installation of
Ozonation System.

DISCUSSION

Elimination of the cyanide concentrations from supply wells #3 and #4 may not be a direct result of ozonation, but rather an indirect result. It is well-known that hexacyanoferrate complexes are very stable to ozonation.[8] In fact, when these materials were used as photographic bleaches, ozonation was employed to reconvert the spent hexacyanatoferrous bleach chemicals to the initial ferric forms, thus allowing recycle and reuse of the spent photographic bleaches.

Injection of ozonized water into the two intrusion wells ahead of supply well #4 creates a diversion in the groundwater flow pattern so that most of the cyanide-containing contaminated water now bypasses supply well #4 (and consequently supply well #3). However, soil samples taken in the vicinity of these two intrusion wells and supply well #4 have shown significant increases in microbiological activities.[6]

Thus a combination of groundwater flow diversion and increased levels of aerobic microorganism activity produce the improvements in water quality noted in supply wells #4 and #3. From the point of view of supply wells #1 and #2, diversion of the flow of contaminated groundwater from the rail marshalling yard has been shown not to be the operative mechanism.[6, 7]

CONCLUSIONS

Groundwaters contaminated with petroleum chemicals and cyanides were removed from the ground and altered in properties by ozonation in such a manner that their reinjection into the ground resulted in an improvement in biological activity in the soil. Biorefractory organic materials were partially oxidized by ozone, producing more readily biodegradable materials.

At the time of publication (1982), the Durlacher Wald water treatment plant had been rejuvenated and had operated successfully for 18 months. More recent information[7] confirms that the process continues to provide high quality drinking water to the citizens of Karlsruhe four years after process installation.

Because of the relative simplicity of the process, it can be adapted to changes in operating conditions and to cope with new contamination problems which may arise. However, it is necessary to have sufficient knowledge regarding the flow of contaminated groundwaters both directionally and with respect to volumes. In addition, the identity of contaminating pollutants should be known as fully as possible to allow determination of the optimum amount of ozone which will be required to convert the pollutants into biodegradable oxidation products prior to reinjection.

The actual purification of the contaminated groundwater takes place in the ground and is only stimulated and improved by the added ozone treatment. Thus, the natural, biological ground purification processes, which are improved and optimized using the added step of chemical oxidation, are employed. As such, the process should be considered by municipalities currently drawing groundwater from contaminated aquifers.

It must be recognized, however, that not all polluting organic materials can be oxidized, even with ozone, at sufficiently reasonable rates to allow them to be converted into biodegradable materials. For example, some of the volatile organic chemicals (VOCs) which have been proposed for regulation by the USEPA (such as chloroform, carbon tetrachloride and tetrachloroethane) are relatively unaffected by ozonation. On the other hand, other VOCs (such as benzene, xylenes, di- and trichloroethylene) are reactive with ozone, and this unique treatment process might be effective in coping with VOC problems involving these types of chemicals.

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AN OVERVIEW OF SOLID WASTE MANAGEMENT IN CHINA

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INTRODUCTION

Solid wastes are inevitable results of productive and consumptive activities of human beings. Wastes are generated in the processes of exploiting natural resources and manufacturing of goods. Those goods also will become wastes after being used or consumed. Associated with urban population growth and production development, the quantities of solid wastes have been dramatically increasing. The annual generation of residential refuses and night soil by 200 million urban people in China amounts to approximately 150 million tons. Industrial wastes have totaled 370 million tons annually, and it has been estimated that the solid wastes may reach 1 billion tons/yr around the year 2000.

In the past, China did not take the management of solid wastes seriously; dumping was the sole method of disposal. Over the years, 540 million tons of solid wastes, covering more than 40,000 ha of land, have been accumulated. Consequently, 17,000 ha of farmland have been contaminated by salts and heavy metals, thus destroying soil texture.

"The Environmental Protection Law (For Trial Implementation)", issued in September 1979, stipulates that "rational use of natural environment, prevention and elimination of environmental pollution and damage to ecosystems" should be ensured; active prevention and control of noxious substances from polluting and damaging the environment are needed. In China, attention has recently been focused on the control and management, present and future, of solid wastes.

POLLUTION IMPACT OF SOLID WASTES

In China, the utilization of mineral resources is at a rate of 50-60%, and utilization of energy resources at 30%. Recently, total quantities of solid wastes generated[1] were over 500 million tons/yr: (unit in million tons/yr)

Waste Type	Amount
Coal Gangue	100
Mineral Tailing	100
Cinder	70
Fly Ash	40
Smelting Slag	40
Residues from Chemical Industry	16
Residential Refuses and Night Soil	146

Dumping requires a vast expanse of land. Owing to management imperfections, residues or ashes from some industries were directly discarded into water bodies. Since the 1950s, that has caused a 1.3 million ha reduction in water surface area of Chinese rivers and lakes.

Only 2% of residential refuses and night soil are treated, and untreated night soil contains a large number of pathogenic bacteria that can threaten human health. Therefore, the municipal wastes are unacceptable to peasants, and disposal of such wastes is becoming more difficult.

Ordinarily, the contamination extends several times beyond the area of uncontrolled dumping. Not only the soil, but also the groundwater will eventually be damaged. It is estimated that there was a 9 billion yuan RMB (Chinese People's Currency) ($3.9 million, US) annual loss as a result of environmental pollution and the failure to recover useable materials.

An example of this is a 1,800 ton heap of residues near a Shanghai Zinc Smeltery. The heap contains 0.03-0.2% cadmium

and the dump site covers 0.7 ha. Surrounding farmland has been damaged by heavy metals. According to measurements of the soil, the average level of cadmium was up to 60 times the background value. Grain planted adjacent to the site was inedible because of its remarkably high content of cadmium. Therefore, the smelter had to be closed down, and measures dealing with the residues are under investigation.

Moreover, considerable amounts of hazardous and toxic substances such as arsenic, chromium, mercury, etc. are washed away without control into the environment, giving rise to contamination problems.

Self-ignition of coal gangue is also a serious problem. Several tons of sulfur dioxide are generated by the combustion and emitted into the air each day.

MANAGEMENT OF SOLID WASTES

It is policy in China that all types of industrial wastes should be reused or be detoxified prior to their disposal. Especially when dealing with hazardous wastes, handling shall be extremely careful to avoid secondary pollution; when handling radioactive wastes, volume reduction and solidification shall be required before ultimate disposal.

On the other hand, the policy of the Government encourages all technologies such as environmental pollution abatement, package, transfer, storage and destruction of hazardous chemicals, and advanced industrial processes that produce less pollution or are even pollution-free.

Comprehensive Utilization

Such practices are rather attractive because many of the wastes or used materials could be reused directly or after simple processing. There are reclamation networks available in most cities in China to collect scrap metals, waste paper, plastics, rubbers and textile. Annually, they turn over 4 billion yuan ($1.7 billion, US) and have net profits of 0.2 billion yuan ($86 million, US).

Coal gangue discarded yearly amounts to 100 million tons. The prediction is that, in 1985, it will be 130-180 million tons/yr. Up to 1 billion tons have been accumulated over the past years. Possible uses include: burning, or utilization in building materials (cement, lime, brick), or using as filler for land reclamation or road making.[2] About 20% of the coal gangue is now being used.

Eighty percent of the slag has been utilized as a raw material in cement at an annual coal savings of 2 million tons and cost saving of about 100 million yuan ($43 million, US)/yr.

Over ten power stations in China have used all their own fly ash. In 1982, 12% of all fly ash produced was utilized by the building material industry. Fly ash generation in Shanghai amounts to about 1 million tons/yr, of which nearly 70% has been beneficially used.

Another use of fly ash is in amelioration of soils; experiments have been ongoing for several years. If fly ash is applied at a rate of 75 to 300 tons/ha, 12-38% and even over 100% increase in production of crops of wheat, paddy, soybean, rape seed, etc., can be expected without any adverse effect of harmful substances.[3]

Tests are being carried out in an attempt to determine beneficial uses for other waste residues. For instance, chromic wastes may be used as coloring matter for glassware or as fillers in building materials after being detoxified. Zhuzhou Smeltery in Hunan Province has achieved an annual profit of 10 million yuan ($4.3 million, US) from recovery of gold, silver and other precious and rare metals out of its own waste residues.

Disposal Practices

Chromic Wastes

Over 2 million tons of chromic residues have accumulated in China. Since enterprises generating the wastes are spread all over the country, disposal is a difficult task. Currently, a requirement that chromic residues be detoxified and/or dewatered before further use or ultimate disposal is being considered. For instance, chromic wastes could be melted at a high temperature to form a kind of glass or be reduceds from Cr(VI) to Cr(III).

In Jinzhou Ferroalloy Mill of Liaoning Province, there was, at one time, a 0.2 million ton dump of 0.5% Cr(VI)-containing residues. This 4 ha open dump had caused groundwater contamination in an area 12.5 km in length and 1 km in breadth. Within this area, water from 1800 wells was found to be unsuitable for drinking. Attempts had been made to dig some interceptor wells downstream from the dump to collect and treat contaminated groundwater. However, those steps failed.[1]

Therefore, a remediation project was begun with an investment of 4.2 million yuan ($1.8 million, US) to construct a concrete barrier for pollution control. The 800 m long barrier penetrates through the earth down to waterproof rock at a maximum depth of 18 m; it rises 2 m above the ground, circling the site. That shape forms an underground "tank" consisting of rocky bottom and impermeable enclosure. The next step is to regulate the groundwater level within the "tank" to hinder the leachate from seeping—by keeping the level in the tank lower than outside it. Downstream, the Cr(VI) containing groundwater is pumped out regularly and treated before discharge. The project was completed in 1982. Nearly 3 months later, Cr(VI) content in the water from the interceptor wells outside the enclosure dropped sharply to 1 to 5% of its prior level, while that from the inside rose several-fold.[4,5] These data indicate that the barrier, to some extent, is effective in pollution control.

Pujiang Chemicals Factory in Shanghai also generates a lot of chromic residues. As a consequence of open dumping, its surroundings and groundwater have been damaged. Thus, a new disposal site is under design, and a leachate recycling plan is being prepared.

The proposal is that a 1.5 m high barrier will be constructed to divide the site into several cells 20 m × 4 m each. The floor and barrier will be of concrete with a pitch liner. On the floor, there will be a series of collection lines to direct the leachate into a tank equipped with pumps to recover the liquid for reuse. Although the system was designed for pollution control via leachate treatment, it also has the advantage of resource reclamation.

Tailings

Tailings from Sanshandao Gold Ore-dressing Mill in Shandong Province contain cyanides and other harmful substances. To eliminate the hazard from seepages, a tailings landfill site has been proposed in the form of an enclosure with each cell 400 m × 400 m in size and 1,000,000 m^3 in volume. Its enclosing wall and bottom are overlain with a waterproof plastic liner. In practice, it is possible to construct a system that will not leak, but if an unfavorable incident occurs, deposited fine tailings would seal off any fissure to stop seepage.

Around the site, a number of interceptor wells are arranged to monitor seepage, or in case of leak to avoid a further spread of pollution by pumping out the contaminated groundwater. That system can be referred to as a kind of hydraulic curtain.

A windbreak will be installed to control dust. Once the site has been filled, it will then be covered with rock, grit and earth and be vegetated. To minimize the quantity of wastewater to be treated, some of the leachate will be collected for reuse. An emergency tank will be installed to receive any overflows of slurry from the tailing conveying system.[4]

Red Mud

Impermeable material is one key in disposal technology. A new kind of red mud compounded material has been developed in China to provide for seepage prevention at red mud disposal sites.[4] It has been determined that 76% of the red mud compounded material has a coefficient of permeability of approximately 10^{-9} cm/sec, freeze- and alkali-proof properties and satisfactory strength to meet the specification required for liner materials in safe landfill disposal.

Radioactive Materials

The general procedure for disposal of radioactive wastes used to involve dewatering or incineration followed by sealing with cement and then deposition in a cave which had been specially designed as an ultimate disposal site. That was unlikely to be a satisfactory long-term solution. Recently, new storage sites for both intermediate and permanent purposes are under consideration.

Generally, radioactive wastes can be classified as high, medium, or low activity, and can be further sorted into flammable or inflammable categories. In agreement with these classifications, the wastes are to be disposed of in different ways. For municipal readioactive wastes in Shanghai (from laboratories, hospitals, etc.), an experimental treatment station is being planned. Apart from its task of handling radioactive waste, the station will also be responsible for development of methodologies and technologies of disposal.

A new incinerator, designed for municipal flammable radioactive waste disposal, is just ready to go into operation. According to its design specifications, it has a treatment capacity of 9 tons/month, beyond the amount of waste generated in Shanghai, and a scrubbing efficiency of 99.99%.

For the inflammable wastes (e.g., contaminated apparatus, instruments, etc.), it is recommended that they be cleaned prior to storage, if possible. A design for a radioactive waste storage facility has been completed, and the project will soon be under construction. It will have a storage capacity of 15 years for the radioactive wastes produced in Shanghai. After being compacted and then packed, the wastes are loaded in steel containers in accordance with their activities and stored in the chambers until ultimate disposal is required.

CONCLUSIONS

According to Chapter 3 of "The Environmental Protection Law (For Trial Implementation)", "discharge of all kinds of harmful substances shall be in compliance with the criteria set down by the State".

Today in China, there is regulated transport for over 6,000 hazardous materials, but there are no particular rules for hazardous wastes. At present, to perfect the management framework in China, a series of regulations for the prevention of pollution and a series of criteria and standards for control objectives are being drawn up, e.g., criteria dealing with residues and sludges for agricultural use, for the building material industry, standards for control of solid wastes from non-ferrous metallic industries, etc.

Safe solid hazardous waste disposal is a pressing issue in China. Disposal technologies, as well as their related techniques, must be investigated and developed.

REFERENCES

1. *Shi Qing Chongqing Environmental Protection, 1,* 1984, 5-8.

2. *Qin Zhigang, Chongqing Environmental Protection, 2,* 1984, 39.

3. East China Testing Institute of Electric Power, "New Approach of Fly Ash Reclamation in Shanghai," First Symposium of Solid Wastes, National Network of Scientific Information of Environmental Protection, China, 1983.

4. Wu Junqing, *et al.,* "Safe Landfill Disposal of Industrial Solid Wastes," Report No. 5, Symposium of Control Standards of Solid Wastes from Non-ferrous Metallic Industries, China, Sept. 1984.

5. Peng Hui, *Environ. Eng., 3,* 1983, 71.

AUTHOR INDEX

SUBJECT INDEX

NATIONAL PRIORITIES LIST—PROPOSED SITES
UPDATE #2, OCTOBER 1984

(Refer to the *Proceedings of the 1983 National Conference on Management of Uncontrolled Hazardous Waste Sites* for the Original NPL and October 1983 Update)

ALABAMA (04)
*Alabama Army Ammunition Plant, Childersburg
*Anniston Army Depot (SE Ind Area), Anniston

ARIZONA (09)
Motorola, Inc., 52nd St. Plant, Phoenix

ARKANSAS (06)
Midland Products, Ola/Birta

CALIFORNIA (09)
Advanced Micro Devices, Inc., Sunnyvale
Alviso Dumping Areas, Alviso
Applied Materials, Santa Clara
Beckman Instruments, Porterville
Fairchild Camera, Mountain View
Fairchild Camera, S. San Jose Plant, South San Jose
Firestone Tire, Salinas
FMC Corp., Fresno
Hewlett Packard, Palo Alto
Intel Corp., Mountain View
Intel Corp., Santa Clara III, Santa Clara
Intel Magnetics, Santa Clara
IBM Corp., San Jose
J.H. Baxter Co., Weed
Lorentz Barrel & Drum Co., San Jose
Louisiana-Pacific Corp.,Oroville
Marley Cooling Tower Co., Stockton
Monolithic Memories, Inc., Sunnyvale
Montrose Chemical Corp., Torrance
National Semiconductor Corp., Santa Clara
Operating Industries, Inc., Lf, Monterey Park
Precision Monolithic, Inc., Santa Clara
Raytheon Corp., Mountain View
San Fernando Valley (Area 1), Los Angeles
San Fernando Valley (Area 2), Los Angeles/ Glendale
San Fernando Valley (Area 3), Glendale
San Fernando Valley (Area 4), Los Angeles
Signetics, Inc., Sunnyvale
Southern Pacific Transportation, Roseville
Teledyne Semiconductor, Mountain View
Thompson-Hayward Chemical Co., Fresno
Van Waters & Rogers, Inc., San Jose
Westingthouse, Sunnyvale
Zoecon Corp/Rhone-Poulenc, Inc., East Palo Alto
*Castle Air Force Base, Merced
* Federal site

*Lawrence Livermore Lab (USDOE), Livermore
*Mather AFB (AC&W Disposal Site), Sacramento
*McClellan AFB (Groundwater Cont.), Sacramento
*Norton Air Force Base, San Bernardino
*Sacramento Army Depot, Sacramento
*Sharpe Army Depot, Lathrop

COLORADO (08)
Eagle Mine, Minturn/Redcliff
Smuggler Mountain, Aspen
Uravan Uranium Project, Uravan
*Rocky Flats Plant (USDOE), Golden
*Rocky Mountain Arsenal, Adams County

DELAWARE
*Dover Air Force Base, Dover

FLORIDA (04)
City Industries, Inc., Orlando
Davidson Lumber Co., South Miami
Dubose Oil Products Co., Cantonment
Montco Research Products, Inc., Hollister
Peak Oil Co./Bay Drum Co., Tampa
Pratt and Whitney Aircraft, West Palm Beach

GEORGIA (04)
*Robins Air Force Base, Houston County

HAWAII (09)
Kunia Wells I, Oahu
Kunia Wells II, Oahu
Mililani Wells, Oahu
Waiawa Shaft, Oahu
Waipahu Wells, Oahu
Waipio Heights Wells II, Oahu

ILLINOIS (05)
Kerr-McGee (Kress Creek) DuPage County
Kerr-McGee (Reed-Keppler Park), West Chicago
Kerr-McGee (Residential Areas), West Chicago
Kerr-McGee (Sewage Treat Plant), West Chicago
NL Industries/Taracop Lead Smelt, Granite City
Pagel's Pit, Rockford
Peterson Sand & Gravel, Libertyville
Sheffield (U.S. Ecology), Sheffield

*Joliet Army Ammunition Plant, Joliet
Sangamo/Crab Orchard NWR (USDOI), Carterville
*Savanna Army Depot Activity, Savanna

INDIANA (05)
Fort Wayne Reduction Dump, Fort Wayne
International Minerals (E. Plant), Terre Haute
MIDCO II, Gary
Neal's Dump (Spencer), Spencer

IOWA (07)
Chemplex Co., Clinton
U.S. Nameplate Co., Mount Vernon
Vogel Paint & Wax Co., Sioux City

KANSAS (07)
Big River Sand Co., Witchita
National Industrial Environ Serv, Furley
Strother Field Industrial Park, Cowley County
Maxey Flats Nuclear Disposal, Hillsboro
Smith's Farm, Brooks

LOUISIANA (06)
*Louisiana Army Ammunition Plant, Doyline

MAINE (01)
*Brunswick Naval Air Station, Brunswick

MARYLAND (03)
Kane & Lombard Street Drums, Baltimore
Mid-Atlantic Wood Preservers, Inc., Harmans
Southern Maryland Wood Treating, Hollywood

MASSACHUSETTS (01)
Haverhill Municipal Landfill, Haverhill
Norwood PCBs, Norwood
Rose Disposal Pit, Lanesboro
Salem Acres, Salem
Shpack Landfill, Norton/Attleboro

MICHIGAN (05)
Avenue "E" Groundwater Contamin, Traverse City
E.I. duPont (Montague Plant), Montague
Lacks Industries, Inc., Grand Rapids
Lenawee Disposal Service, Inc. Lf, Adrian
Michigan Disposal (Cork St Lf), Kalamazoo
Motor Wheel, Inc., Lansing
North Bronson Industrial Area, Bronson
Roto-Finish Co., Inc., Kalamazoo

South Macomb Disposal (Lf #9), Macomb Township
Thermo-Chem, Inc., Muskegon
Torch Lake, Houghton County
Waste Management (Holl Lagoons), Holland
Adrian Municipal Well Field, Adrian
Agate Lake Scrapyard, Fairview Township
Koch Refining Co./N-Ren Corp., Pine Bend
Kummer Sanitary Landfill, Bemidji
Kurt Manufacturing Co., Fridley
Long Prairie Groundwater Contam, Long Prairie
Oak Grove Sanitary Landfill, Oak Grove Township
Olmsted County Sanitary Landfill, Oronoco
Pine Bend/Crosby American Lf, Dakota County
U of Minnesota Rosemount Research Cent, Rosemount
Windom Dump, Windom

MISSISSIPPI (04)
Newsom Brothers/Old Reichhold, Columbia

MISSOURI (07)
Bee Cee Manufacturing Co., Malden
Findett Corp., St. Charles
Lee Chemical, Liberty
North-U Drive Well Contamination, Springfield
Quality Plating, Sikeston
Solid State Circuits, Inc., Republic
*Lake City Army Plant (NW Lagoon), Independence
*Weldon Spring Quarry (USDOE/Army), St. Charles County

MONTANA (08)
Burlington Northern (Somers Plant), Somers
Idaho Pole Co., Bozeman
Mouat Industries, Columbus

NEBRASKA (07)
Hastings Groundwater Contamin, Hastings
Lindsay Manufacturing Co., Lindsay
Waverly Ground Water Contamin, Waverly
*Cornhusker Army Ammunition Plant, Hall County

NEW HAMPSHIRE (01)
Coakley Landfill, North Hampton

NEW JERSEY (02)
Cinnaminson Ground Water Contam, Cinnaminson
Fried Industries, East Brunswick Township
Glen Ridge Radium Site, Glen Ridge
Jame Fine Chemical, Bound Brook
Lodi Municipal Well, Lodi
Montclair/West Orange Radium Site, Montclair/West Orange
Pomona Oaks Residential Wells, Galloway Township
Waldick Aerospace Devices, Inc., Wall Township
*Fort Dix (Landfill Site), Trenton
*Naval Weapons Stat Earle (Site A), Colts Neck

NEW YORK (02)
Anchor Chemicals, Hicksville
Applied Environmental Services, Glenwood Landing
Byron Barrel & Drum, Byron
BEC Trucking, Town of Vestal
Claremont Polychemical, Old Bethpage
Clothier Disposal, Town of Granby
* Federal site

Colesville Municipal Landfill, Town of Colesville
Cortese Landfill, Village of Narrowsburg
Endicott Village Well Field, Village of Endicott
FMC Corp. (Dublin Road Landfill), Town of Shelby
Goldisc Recordings, Inc., Holbrook
Haviland Complex, Town of Hyde Park
Hertel Landfill, Plattekill
Hooker Chemical/Ruco Polymer Corp, Hicksville
Johnstown City Landfill, Town of Johnstown
Katonah Municipal Well, Town of Bedford
Kenmark Textile Corp., Farmingdale
Liberty Industrial Finishing, Farmingdale
Nepera Chemical Co., Inc., Maybrook
North Sea Municipal Landfill, North Sea
Pasley Solvents & Chemicals, Inc., Hempstead
Preferred Plating Corp., Farmingdale
Robintech, Inc./National Pipe Co., Town of Vestal
Sarney Farm, Amenia
Suffern Village Well Field, Village of Suffern
SMS Instruments, Inc., Deer Park
Tronic Plating, Co., Inc., Farmingdale
Volney Municipal Landfill, Town of Volney
*Griffiss Air Force Base, Rome

NORTH CAROLINA (04)
Bypass 601 Groundwater Contam, Concord
Celanese (Shelby Fiber Operations), Shelby
Jadco-Hughes Facility, Belmont
NC State U (Lot 86, Farm Unit #1), Raleigh

OHIO (05)
Alsco Anaconda, Gnadenhutten
General Electric (Coshocton Plant), Coshocton
Industrial Excess Landfill, Uniontown
Republic Steel Corp. Quarry, Elyria
Sanitary Landfil Co. (IWD), Dayton
Van Dale Junkyard, Marietta

OREGON (10)
Martin-Marietta Aluminum, Inc., The Dalles
*Umatilla Army Depot, Hermiston

PENNSYLVANIA (03)
Ambler Asbestos Piles, Ambler
Brown's Battery Breaking, Shoemakersville
Domino Salvage Yard, Valley Township
Hunterstown Road, Straban Township
Middletown Air Field, Middletown
Modern Sanitation Landfill, Lower Windsor Township
Shriver's Corner, Straban Township
Westinghouse Elevator Co. Plant, Gettysburg
Whitmoyer Laboratories, Jackson Township
*Letterkenny Army Depot (SE Area), Chambersburg

RHODE ISLAND (01)
Central Landfill, Johnston

TENNESSEE (04)
American Creosote Works, Inc., Jackson
*Milan Army Ammunition Plant, Milan

TEXAS (06)
Bailey Waste Disposal, Bridge City
Brio Refining Co., Inc., Friendswood
Crystal City Airport, Crystal City
Koppers Co., Inc. (Texarkana Plant), Texarkana
North Calvacade Street, Houston
Odessa Chromium #1, Odessa

Odessa Chromium #2 (Andrews Hgwy), Odessa
Pesses Chemical Co., Fort Worth
Petro-Chemical (Turtle Bayou), Liberty County
Sol Lynn/Industrial Transformers, Houston
South Cavalcade Street, Houston
Stewco, Inc., Waskom
*Air Force Plant #4 (Gen Dynamics), Fort Worth
*Lone Star Army Ammunition Plant, Texarkana

UTAH (08)
Mayflower Mountain Tailings Ponds, Wasatch County
Monticello Rad Contaminated Props, Monticello
Olson/Neibart Reservoir, Wastach County
Portland Cement (Kiln Dust 2 & 3), Salt Lake City
Sharon Steel (Midvale Smelter), Midvale
*Hill Air Force Base, Ogden
*Odgen Defense Depot, Ogden
*Tooele Army Depot (North Area), Tooele

VIRGINIA (03)
Avtex Fibers, Inc., Front Royal
Culpeper Wood Preservers, Inc., Culpeper
IBM Corp. (Masassas Plant Spill), Manassas
L.A. Clarke & Son, Spotsylvania County
Rhinehart Tire Fire Dump, Frederick County
*Defense General Supply Center, Chesterfield County

WASHINGTON (10)
Mica Landfill, Mica
Midway Landfill, Kent
Northside Landfill, Spokane
Northwest Transformer, Everson
Quendall Terminal, Renton
Silver Mountain Mine, Loomis
Toftdahl Drums, Brush Prairie
*Bangor Ordnance Disposal, Bremerton
*Fort Lewis (Landfill No. 5), Tacoma
*McChord AFB (Wash Rack/Treatment), Tacoma

WEST VIRGINIA (03)
Mobay Chemical (New Martinsville), New Martinsville
Ordnance Works Disposal Areas, Morgantown

WISCONSIN (05)
Fadrowski Drum Disposal, Franklin
National Presto Industries, Inc., Eau Claire
Stoughton City Landfill, Stoughton

Total Sites Listed: 244

SITES CONTINUED TO BE PROPOSED FROM UPDATE # 1

GEORGIA (04)
Olin Corp. (Areas 1, 2 & 4), Augusta

OKLAHOMA (06)
Sand Springs Petrochemical Cmplx., Sand Springs

TEXAS (06)
Pig Road, New Waverly

MISSOURI (07)
Quail Run Mobile Manor, Gray Summit

1984 EXHIBITORS

ACES
115 Gibraltar Road
Horsham, PA 19044   215/441-5924

Associated Chemical and Environmental Services (ACES) is one of the nation's largest hazardous material and waste handling contractors with over 20 years of experience in site remediation, spill cleanup, and industrial maintenance. ACES has over 300 clients with projects distributed in both the public and private sectors. Work activity takes ACES to any of the 48 continental United States. In addition to site cleanup services, ACES provides waste water treatment, physical/chemical waste stabilization, and underground storage tank remediation.

AIR-TECH Industries, Inc.
Post Office Box 507
East Rutherford, NJ 07073   201/460-9730

AIR-TECH Industries, Inc., East Rutherford, NJ, has over 25 years of manufacturing experience in fabric structure technology and offers a wide range of air supported structures and tension structures specifically designed to meet the requirements of covering waste sites for removal of contaminated material. AIR-TECH is now actively participating in USEPA Superfund projects.

ALERT, INC.
P.O. Box 208
Canton, OH 44701   216/454-8304

Independent environmental testing laboratories with mobile analytical capabilities. Headquarters laboratory offers complete organic and inorganic analysis of waste, water, etc. with overnight emergency turnaround. Mobile units equipped with G.C./M.S., G.C., atomic absorption and air monitors for lab packing, waste screening, landfill assessment and chemical spills. Experienced Superfund and ERCS subcontractor.

Acres American Incorporated
1000 Liberty Bldg.
424 Main Street
Buffalo, NY 14202   716/853-7525

Acres American Incorporated, an internationally known consulting engineering and project management firm, provides services to the solid and hazardous waste industry including: hydrogeological investigations, groundwater monitoring and evaluations, design of TSDF facilities and remediation programs, and facility closure planning.

AeroVironment, Inc.
145 Vista Ave.
Pasadena, CA 91107   818/449-4392

Hazardous waste site investigations and toxic air pollutant studies. Special field studies; simulation modeling of groundwater and air; air pollutant permit analyses; expert testimony.

Air Pollution Control Association
P.O. Box 2861
Pittsburgh, PA 15230   412/621-1090

Publications and member services in the areas of hazardous waste management and air pollution control.

American Resources Corp.
850 West Valley Forge Road
King of Prussia, PA 19406   215/227-7373

American Resources provides services and proprietary technology for the fixation/solidification of industrial wastes, including in situ closure of impoundments and design or operation of dedicated processing facilities. The technology is currently marketed under the PERMIX™ tradename.

American Technological Industries, Inc.
25 S. Shore Dr., P.O. Box 1726
Toms River, NJ 08754   201/255-5163, 5900

American Technological Industries, Inc., is a hazardous waste management firm offering transportation services, removing and disposal of industrial and governmental waste. Our customers include many of the Fortune 500 companies in the U.S. and various state and federal agencies involved with waste removal.

Analytical Instrument Development
Route 41 & Newark Road
Avondale, PA 19311   215/268-3181

Analytical Instrument Development manufacturers portable instrumentation for the determination of trace organic materials in the environment. The Model 511 portable gas chromatograph with electron capture detection for PCBs in soil will be on exhibit. In addition AID's new Model 590 GC/OVM for total organic vapors (OVM) or specific materials (GC) in air will be shown. Other AID instruments for on-site organic measurements at waste sites will also be displayed.

Aspen Systems Corporation
1600 Research Blvd.
Rockville, MD 20850   301/251-5229

Hazardous Waste Report—Newsletter Service

BCM Eastern Inc.
Plymouth Meeting Mall
Plymouth Meeting, PA 19462   215/825-3800
                                        ext. 360

Facilities design and environmental engineering specializing in hazardous waste management and remediation.

Baron-Blakeslee, Inc.
2001 N. Janice Avenue
Melrose Park, IL 60160   312/450-3913

Air stripping towers for volatile organic compound removal from water.

Bergen Barrel & Drum Co.
43-45 O'Brien Street
Kearny, NJ 07032   201/998-3500

Bergen Barrel's "Super Shipper" line of closed head polyethylene drums is available in a 15 through 55 gallon size. Our open top line of polydrums is available in a 14 through 55 gallon size. Both lines of polydrums are DOT approved for hazardous waste.

Biospherics Incorporated
4928 Wyaconda Road
Rockville, MD 20852   301/770-7700

Biospherics provides quality and responsive analytical services by state-of-the-art methodologies. The Laboratory utilizes 25,000 sq. feet of space equipped with GC/MS, GC, AA, TOX, TOC, HPLC, IR, UV-VIS autoanalyzer and full wet chemistry capabilities. Biospherics provides programs for priority-pollutant analyses; RCRA, NPDES, and NIPDWR compliance; Industrial Hygiene testing, sampling and consultation; wastewater treatment; treatability and pilot plant studies; aquatic bioassays and environmental field studies.

Bregoil Sponge International, Inc.
3501 Launcelot Way
Annadale, VA 22003   703/560-7409
                                373-3482

Bregoil Sponge International, Inc., is the manufacturer of Bregoil which is a product processed from wood cellulose fibers and has millions of capillary traps or pockets. These hold confined hydrocarbons, oils, and many chemical wastes while they float and repel water. Bregoil spread and not retrieved degrades to organic mulch much as a plant's root. The saturated kernels of Bregoil may be buried or incinerated with negligible ash.

The Bureau of National Affairs, Inc.
1231 25th Street, NW
Washington, DC 20037   202/452-4452

Since 1970, with the launch of *Environment Reporter*, BNA's environmental protection and safety information services have set the standard of excellence. From the wide perspective of *Environment Reporter* to the new *International Hazardous Materials Transport Manual*, BNA fills a vital need for factual information throughout the environment and safety fields.

CECOS International
2321 Kenmore Avenue
Buffalo, NY 14207   716/873-4200

CECOS International, with corporate headquarters in Buffalo, NY, is the technological leader in the chemical and hazardous waste management field specializing in the safe disposal and management of toxic and hazardous wastes. CECOS' current capabilities and services include secure chemical management facilities (SCMF), wastewater treatment facilities, acid neutralization, lime reclamation, fuels blending, solidification, PCB transformer decommissioning, deep well injection and several ancillary services.

CH2M HILL, Inc.
1941 Roland Clark Place
Reston, VA 22091   703/620-5200

Founded in 1946, CH2M HILL is one of the largest engineering firms in the United States with a staff of over 2,000 men and women. We provide comprehensive study, design, and construction management services for technological systems that include water, waste management, agriculture, energy, industry, transportation, and civil engineering.

California Analytical Labs, Inc.
2544 Industrial Blvd.
West Sacramento, CA 95691   916/372-1393

CAL Labs' staff (4 PhD and 30 BS/MS level chemists) and equipment (7 GC/MS, 15 GC, 3 AA, 1 ICP) occupy 25,000 sq. feet of lab space in Sacramento, CA. CAL Labs performs analyses of hazardous wastes for federal and state regulatory agencies as well as private and industrial clients. CAL Labs now operates a Finnigan 8222 high resolution GC/MS system, particularly useful for TCDD measurements.

Camp Dresser & McKee
One Center Plaza
Boston, MA 02108   617/742-5151

Camp Dresser & McKee (CDM) provides engineering and management services to public and private clients responsible for managing environmental resources, facilities, and infrastructure. CDM has conducted site investigations and feasibility studies and provided design and construction management services at approximately 100 hazardous waste sites in the United States.

Century Laboratories, Inc.
1501 Grandview Ave.
Thorofare, NJ 08086   609/848-3939

Century Laboratories, Inc. is a full service, full 24 hour operation laboratory specializing in all areas of environmental testing and field service work. The firm's capabilities include: extensive experience in the evaluation of hazardous waste, toxic chemicals, and soils analysis utilizing such state-of-the-art analytical tools in priority pollutant analysis, complete RCRA testing EP toxicity analysis, and bioassay determinations. To complete our full service capabilities we aid our clients in preparation of bids, manifests, report writing and data evaluation. Field service teams for collecting both air and waste samples are available for on-site work throughout the United States.

Chemfix Technologies, Inc.
Post Office Box 1572
Kenner, LA 70063   504/467-2800

Chemfix Technologies, Inc., (CTI) offers the patented CHEMFIX® Process for the chemical fixation/stabilization of both hazardous and non-hazardous liquid and sludges. Complete mobile project services are offered, as well as fixed plant facilities for continuous generation waste streams. CTI services include site assessment, waste stream characterization, and engineering and permitting support.

Chemical Waste Management, Inc.
   ENRAC Division
3003 Butterfield Road
Oak Brook, IL 60521   312/654-8800

ENRAC serves industry and regulatory agencies in all aspects of hazardous waste mitigation. ENRAC's network of analytical laboratories, specialized on-site equipment, transportation fleet, and past experience in all phases of remedial action from site investigations to surface and sub-surface cleanup, support its capability to handle situations from emergency spills, and plant cleanups to large-scale remedial action.

Chem-Met Services
18550 Allen Road
Wyandotte, MI 48192   313/282-9250

Chem-Met Services provides environmentally safe treatment fo liquid and solid wastes. Since 1966 we have provided an ecologically sound and economically efficient process of stabilizing waste streams. As a client-oriented company we enjoy processing acids, alkalis, adhesives, paints, oils, phosphates, resins, plastisols, solvents, sludges and other hazardous wastes into an *inert solid*.

Clayton Environmental Consultants, Inc.
25711 Southfield Road
Southfield, MI 48075   313/424-8860

Clayton Environmental Consultants, a nationally recognized consulting firm, assists in developing waste management action plans and strategies, including: air, water, and earth hazardous contaminants studies; accredited and licensed analytical services; hydrogeological investigations; expert testimony; environmental risk assessments; inactive hazardous waste site investigations, and many more.

CompuChem Laboratories
P.O. Box 12652
Research Triangle Park, NC 27709   800/334-8525

CompuChem Laboratories is the world's largest laboratory specializing in Hazardous Waste Analysis by GC/MS. With its extensive experience in the field, CompuChem is able to provide a range of analytical laboratory services to meet the needs of clients in the following areas: Superfund waste site analysis; RCRA; priority pollutant analysis; identification of unknown wastes; groundwater monitoring; dioxin analysis;
continued on attached sheet—DAN-there is no attached sheet!!

Crown Zellerbach
Nonwoven Fabrics Division
3720 Grant St.
Washougal, WA 98671   800/426-0700

Crown Zellerbach's Fibretex display booth offers product development literature, specifications, application guides and samples of Fibretex geotextile fabrics. Fibretex provides protection to geomembranes in ponds, landfills and reservoirs by: cushioning against surface abrasion or puncture from sharp rocks; providing lateral venting of subgrade gases to avoid floating or rupture.

Cytox/Polybac Corporation
954 Marcon Blvd.
Allentown, PA 18103   215/264-8740

Cytox/Polybac Corporation develops and manufactures specialized bacteria, enzymes, specialty chemical formulations and equipment systems for application in pollution control and agriculture.

Darell Bevis Associates, Inc.
Route 2, Box 311
Sterling, VA 22170   703/430-7100

Darell Bevis Associates, Inc. provides services and products in Occupational Respiratory Protection and Hazardous Materials Response. Training courses include: Occupational Respiratory Protection and Protecting HazMat Response Personnel. Consultation services include: expert witness testimony, research studies, fit testing, program audits, and custom designed training courses and audiovisuals. Also available are audiovisual programs and publications.

Dunn Geoscience Corporation
5 Northway Lane North
Latham, NY 12110   518/783-8102

Dunn Geoscience Corporation, Geologic and Hydrologic Consultants: hazardous waste site assessment and remediation services include: geophysical surveys; aquifer pump tests; groundwater sampling; groundwater modeling; computerized data analysis; regulatory compliance assistance. Offices in Albany, Buffalo, Laconia and Harrisburg.

EA Engineering, Science, and
   Technology, Inc.
15 Loveton Circle
Sparks, MD 21152   301/771-4950

EA Engineers and Scientists provide assistance in complying with environmental regulations and protection objectives of our clients in industry and government in the following areas: planning; applied research; engineering design; site assessments and field investigations; environmental engineering; toxic and hazardous materials management; planning, regulatory liaison and compliance monitoring; and environmental risk management.

EAL Corporation
2030 Wright Avenue
Richmond, CA 94804   415/235-2633

EAL Corporation provides consulting and analytical services in the technical fields of environmental science, occupational health and safety, and nuclear science. EAL's exhibit shows how industry and government agencies, as well as the consulting engineering profession, can utilize EAL's services to support their hazardous waste programs.

ENRECO, Inc.
5772 Canyon Drive
Amarillo, TX 79109   806/359-3511

ENRECO, Inc., uses specially designed equipment to inject and thoroughly mix fixation/solidification chemicals into existing waste lagoons. These chemicals convert the liquid or semi-liquid waste into a solid soil-like material. Our process has been used for remedial action as well as for treatment of waste prior to landfilling on site.

ENSCO, Inc.
1015 Louisiana Street
Little Rock, AR 72202   501/375-8444

A full PCB service company: high temperature incineration of PCBs, solids, liquids and capacitors; transformer decommissioning; emergency response; mobile incineration; and groundwater decontamination.

ERT
696 Virginia Rd.
Concord, MA 01742   617/369-8910

Complete environmental consulting and technical/engineering services—air, water, waste. Hazardous waste management and consulting services: Superfund and RCRA consulting; waste analysis and delisting assistance; audits; permitting; closure and post-closure planning; inactive waste disposal site assessments/characterizations; remedial action programs; groundwater modeling and monitoring; risk assessments; toxic air pollutant measurement and analysis; emergency response systems.

ESE, Inc.
P.O. Box ESE
Gainesville, FL 32604 904/332-3318

ESE, a full service multidisciplinary environmental engineering firm, has performed work at more than 120 hazardous waste sites including 15 CERCLA NCP sites. Capabilities include: remedial investigations; feasibility studies; QA/QC plans; safety and health planning and monitoring; community relations; analytical services; and expert witness testimony.

E.C. Jordan Co.
562 Congress Street
Portland, ME 04112 207/775-5401

Solid and hazardous waste management services provided to industry and government agencies include: geophysical and geohydrological investigations; record searches; chemical characterization; contamination risk assessment; identification and evaluation of remedial action alternatives and implementation plans at hazardous waste sites. Hazardous waste TSD facilities are developed from initial planning stages, through site selection and investigation, design, permit application and construction management.

Ecology and Environment, Inc.
P.O. Box D
Buffalo, NY 14225 716/632-4491

Ecology and Environment is America's leading consultant for management of hazardous wastes and environmental emergency responses. Complete field investigation, monitoring, cleanup, analytical and engineering services are available for industrial and government clients throughout the United States and abroad.

E.I. duPont deNemours & Co.
Tech. Lab., Chambers Works
Deepwater, NJ 08023 609/540-3884

Wastewater treatment service.

Element Analysis Corp.
1696 Capital Circle SW
Tallahassee, FL 32304 904/576-5115

Element Analysis Corporation (EAC) is a commercial analytical laboratory featuring analysis by proton induced x-ray emission (PIXE). PIXE is a simultaneous, non-destructive technique for analyzing a sample for the elements from sodium through uranium. Sample matrices may vary from solids (soils, powders, etc.) to liquids and aerosol filters. In addition to PIXE, EAC also offers a wide variety of other analytical techniques, including atomic spectroscopy, gaschromotography and wet laboratory techniques.

Engineered Textile Products, Inc.
P.O. Box 7474 205/476-8001
Mobile, AL 36607 800/222-8277

E.T.P. is a manufacturer/fabricator of industrial textile products. The principal products are pit and pond liners, floating baffles, covers, large tarpaulins, etc. Main plant offices Mobile, AL.—branches in other cities.

Engineering-Science
57 Executive Park South, Suite 590
Atlanta, GA 30329 404/325-0770

Engineering-Science is a leading international environmental engineering firm offering full services in solid waste management, hazardous waste remedial design and implementation, permitting, air pollution services, waste water treatment, hydrogeological and geophysical studies, field services and laboratory analyses. Through offices in major cities, Engineering-Science provides services to clients in the government, military and private sectors.

Evergreen Industries
6390 Joyce Drive
Golden, CO 80403 800/525-8696

Portable personnel decontamination units for hazardous materials. Manufactured according to customer specifications. No decontamination unit is too large or too small for Evergreen Industries to service your decontamination needs. We can handle everything from asbestos to radioactive material correctly.

Federal Emergency Management Agency
500 C Street, S.W.
Washington, DC 20472 202/287-0300

The exhibit is titled "Integrated Emergency Management Systems." This exhibit features electronic displays of potential hazard areas in the United States.

Fram Industrial Filter Corporation
Post Office Box 33210
Tulsa, OK 74153 918/252-9571

Fram Industrial coalescing plate separators will be exhibited. Fram Industrial manufactures a complete range of gravity and pressurized separators. There are no filter cartridges or disposable elements used in Fram CPS systems. Many hazardous waste elements carried by wastewater can be effectively removed in a Fram CPS Separator system. Fram experience can help you win the wastewater battle.

Fred S. James & Co., Inc.
230 W. Monroe St., 19th Floor
Chicago, IL 60606 312/726-4080

"Act 1, Scene II"—Fred S. James & Co., a proven leader in the insurance brokerage business, is able to provide your company with a complete range of brokerage and insurance consultation services, including expert advise on environmental impairment liability insurance and technical assistance in the areas of hazardous material handling control and disposal, all designed to ensure that your company is in compliance with existing federal and state financial responsibility laws and that its assets are adequately protected in the event of an unexpected release of pollutants or contaminants into the environment.

GAI Consultants, Inc.
570 Beatty Rd.
Monroeville, PA 15146 412/856-6400

GAI Consultants, Inc. and its subsidiaries provide engineering consulting services in the areas of solid and hazardous waste management, federal and state permitting assistance, and disposal site design services including remedial investigations and feasibility studies, geohydrologic investigations, site selection and cost optimization evaluations, and site operation and closure plans.

GCA/Technology Division
213 Burlington Road
Bedford, MA 01730 617/275-5444

CERCLA-related remedial engineering, field sampling, laboratory analysis and groundwater monitoring and modeling. Mobile hazardous waste analytical laboratories. Site investigations and air toxics monitoring. Complete RCRA permit application assistance. Incinerator trial burns. Closure and post-closure plans. Registered engineers, geologists and industrial hygienist. AIHA Certified Laboratory.

Galson Technical Services, Inc.
6601 Kirkville Rd.
E. Syracuse, NY 13057 315/432-0506

Galson Technical Services, Inc. was founded in 1970 to provide services in the field of environmental science. The Galson staff includes experienced environmental scientists, engineers, chemists, industrial hygienists and meteorologists. Galson offers services from our San Francisco and Syracuse offices in the areas of: industrial hygiene, laboratory analysis, source emission testing, dispersion model-

ing, meteorological studies, ambient air monitoring, environmental impact assessment and hazardous waste management.

Geo-Con, Inc.
Post Office Box 17380
Pittsburgh, PA 15235 412/244-8200

Specialty construction service company in hazardous waste containment contracting, including pond liners, slurry walls, grouting and other techniques related to containment of fluids and underground seepage.

Geonics Limited
1745 Meyerside Drive, Unit #8
Mississauga, Ontario
L5T 1C5 Canada 416/676-9580

Geonics Limited is the world's leading manufacturer of electromagnetic geophysical equipment for the direct detection of ore bodies and geological mapping. These same geophysical methods have proven to be invaluable for the detection of buried metallic drums and for mapping groundwater contaminant plumes. A wide range of ground conductivity meters can be seen at the Geonics Booth.

Groundwater Decontamination Systems, Inc. 103
12 Industrial Park
Waldwick, NJ 07463 201/445-3141

Patented in situ process for biodegrading hydrocarbons and halogenated hydrocarbon contaminants in ground and groundwater. The GDS system effectively decontaminates both soil and groundwater, making it more efficient, faster and less expensive than other available methods. It is a complete solution.

Gundle Lining Systems, Inc.
1340 E. Richey Road
Houston, TX 77073 713/443-8564

Gundle Lining Systems, Inc., a full service company manufacturing, installing and welding on-site high density polyethylene (HDPE) sheeting in thicknesses ranging from 20 mil to 100 mil and widths of 22.5 ft. These flexible membrane liners are used for applications pertaining to environmental protection such as irrigation dams, reservoirs, sanitary landfills, sewage containment, earth canals and hazardous and non-hazardous waste containments. Gundle has also announced their manufacturing of two new products, Driline and Hyperlastic.

HAZCO
1347 E. Fourth St.
Dayton, OH 45402 513/222-1277

HAZCO is a total service supplier of all equipment, training and program development needed for safe handling of hazardous materials. Services include: safety/health equipment sales; rental of decon and equipment trailers, OVAs, HNU and SLBA. HAZCO's Techservice is available at 1-800-332-0435 to offer alternatives for specific safety/health concerns.

H2M/Holzmacher, McLendon & Murrell, P.C.
125 Baylis Road, Suite 140
Melville, NY 11747 516/752-9060

Environmental analyses including industrial/hazardous wastes, air, water, wastewater, sludge, soils, leachate, dredge spoils. Capabilities include: bacteriology; wet and automated chemistry; gas chromatography; atomic adsorption spectrophotometry and GC/MS. Consulting engineering and environmental services including: impact assessments; NPDES monitoring; treatment/disposal technology; RCRA compliance; regulatory permit administration. USEPA and State(s) Approved Laboratory.

HNU Systems, Inc.
160 Charlemont St.
Newton, MA 02161 617/964-6690

Model 301 gas chromatograph—a portable version of the 301 with DC power/gas supply option pro-

vides field investigation capabilities. This G.C. can be equipped with both photoionization detector which provides field confirmation of unknown species. Model PI-101 hazardous waste detector provides immediate indication of the presence of potential toxic chemicals, even at sub ppm levels, and gives a breakdown of existing compounds when used with three available probes.

Harding Lawson Associates
7655 Redwood Blvd.
P.O. Box 578
Novato, CA 94948   415/892-0821

Services: hazardous waste site investigations; hydrogeological investigations; aquifer restoration; leak detection; plume mapping; feasibility studies; risk assessment; environmental audits; facility design. Disciplines: hydrogeology; hydrology; geology; geochemistry; geophysics; environmental engineering; geotechnical engineering; chemical engineering.

Hazardous Materials Control Research Institute
9300 Columbia Boulevard
Silver Spring, MD 20910   301/587-9390

HMCRI is a unique, public, nonprofit, membership organization which promotes the establishment and maintenance of a reasonable balance between expanding industrial productivity and an acceptable environment. Our goals are met through a variety of publications, conferences, workshops, newsletters, equipment exhibitions and other information dissemination programs. We provide members and all other interested persons with a distinctive forum in which they can exchange information and experiences dealing with hazardous materials. *Join HMCRI today!!*

Hazardous Waste Technology Services (HazTech)
3300 Marjan Drive
Atlanta, GA 30340   404/451-9877

HazTech specializes in hazardous waste site cleanup and emergency spill response. Its offices in Atlanta and Tampa are staffed with teams of professionals in operation's crews that are highly experience in sampling, handling, treatment and removal of hazardous materials. HazTech is currently an EPA Emergency Response Cleanup Services (ERCS) contractor.

Health Evaluation Programs, Inc.
808 Busse Highway
Park Ridge, IL 60068   312/696-1824

Health Evaluation Programs, Inc. provides nationwide Mobile Health Testing Services, Health Status Profile Appraisals, a Hearing Conservation Program, and lab analysis for drugs of abuse, alcohol and marijuana. HEP is also introducing a new program this year called "Back in Health"—a back injury program.

Hoyt Corporation
251 Forge Road
Westport, MA 02790   617/636-8811

The Hoyt Odor-Miser is a prefabricated granulated activated carbon filter engineered to remove low concentration odors, toxic substances, irritants, corrosive vapors and other gases from vent systems. Odor-Misers under normal circumstances will eliminate obnoxious odors from a wide range of solvents and other organic and inorganic emissions. The Hoyt Still is a solvent purification and distillation system engineered for simple solution to contaminated solvent disposal problems. This unit has a stainless steel distillation tank, stainless steel condensor coil and heater coil.

ICF Incorporated
1850 K Street, NW, Suite 950
Washington, DC 20006   202/862-1100

ICF is an employee owned consulting firm specializing in economic policy, engineering and scientific analyses for public and private clients. The 150 con-

sultants in environmental practice focus on hazardous substance control and waste management, providing risk assessments, cost analyses, regulatory analyses, and related services to our clients. Other major environmental consulting analyses include toxic substances, air and water pollution control.

ICOS Corporation of America
4 W. 58th St.
New York, NY 10019   212/688-9216

Slurry walls, slurry trenches, drilling, grouting, bored piles, load bearing elements, tieback anchors, sewer rehabilitation, shotcrete, Envirowall.

ISCO, Environmental Division
P.O. Box 82531
Lincoln, NE 68501   402/474-2233

Dedicated and portable well samplers, wastewater samplers and open channel flow meters will be exhibited. The Model 2600 Well Sampler, which has pumping rates to 2.2 gpm, is designed to fit into 2-inch well casings. Well caps and quick disconnect fittings are available for dedicated installations.

Industrial Training Systems Corp.
823 East Gate Drive
Mt. Laurel, NJ 08054   609/234-2600

Industrial Training Systems Corp. designs, develops, produces and markets mixed media training materials in the area of environmental and occupational health and safety. We offer training programs on RCRA, TSCA, Compliance Awareness and a seven-part series (live video) on hazardous spill management. Also programs on health hazard communication employee training.

In-Situ, Inc.
209 Grand Avenue
Laramie, WY 82070   307/742-8213

Computer-automated groundwater level monitoring instrumentation. Multidisciplinary services: metallurgical and analytical laboratories; hydrologic and geotechnical consulting; feasibility studies and process design; computer timesharing; hydrologic and energy related software for the IBM PC; graphic software; oil and gas and mining software.

International Engineering Company Morrison-Knudsen Co.
180 Howard Street
San Francisco, CA 94105   415/442-7300

International Engineering Company/Morrison-Knudsen Company provides site investigations, remedial designs, construction management and remedial actions. Site investigations include: ground and surface water monitoring; definition of hydrologic regime; site geology and contaminant transport. Remedial design includes: slurry trench design; encapsulation; site drainage improvements; cost estimates; specifications; drawings and feasibility studies.

International Marketplace/ Hospitality Booth

A distinctive area for conference attendees, exhibitors, guests, special dignitaries and international representatives to convene during the Conference and Exhibition. HMCRI is extremely pleased and proud to have this important and timely international portion of the 5th Superfund Convention, and everyone in attendance is encouraged to visit this area to become more acquainted with the activities of our international counterparts.

JRB Associates
A Company of SAIC
8400 Westpark Drive
McLean, VA 22102   703/821-4886

JRB, a Company of Science Applications International Corporation, is pleased to demonstrate its experience and expertise in the management of hazardous wastes including site investigation, RCRA "Part B" Permit applications, chemical industry studies, technology evaluation for hazardous spill

cleanup and site remediation. Additional services include environmental audits, expert witness testimony and regulatory development.

James T. Warring Sons, Inc.
4545 "S" Street
Capital Heights, MD 20743   301/322-5400

All types and sizes of containers—new & reconditioned—fiber, steel, plastic. Our hazardous waste containers are DOT approved and range in size from 5 to 83 gallons. We accept orders from one to truck loads and we ship anywhere. You order a container—we don't have it—it's special—we will get it for you. No order is too small for James T. Warring Sons, Inc. Let us help you contain your hazardous waste. We can it!

J.J. Keller & Associates, Inc.
145 West Wisconsin Avenue
Neenah, WI 54956   414/722-2848

Technical publisher and regulatory services company specializing in consulting and safety services, transportation and hazardous material/waste publications, forms and supplies. Our product line includes: guides, manuals, training materials, placards, labels, spill control devices, wall charts, hazardous waste manifests, and bills of lading. We also offer a full line of products to solve most any transportation or hazardous material/waste problem. We can service your needs. Phone: national 800/558-5011; Wisconsin 800/242-6469; local 414/722-2848.

K.W. Brown and Associates, Inc.
6A Graham Rd.
College Station, TX 77840   409/693-8716

K.W. Brown and Associates, Inc. (KWB&A) has a multidisciplinary staff of professionals who can provide the state-of-the-art expertise needed to develop solutions to your environmental management and pollution needs. KWB&A specializes in soil related aspects of the storage, treatment and disposal of both hazardous and nonhazardous wastes, cleanup assessment of salt and chemical spills, compatibility testing of clay liner-waste combinations, reclamation of disturbed lands and interpretation of soil analyses. Through research and consulting, KWB&A has developed an in-depth understanding of the movement and degradation of chemical compounds and plant nutrients in the soil environment, which is an essential part of the solution to many environmental problems. KWB&A has provided assistance to numerous clients, including petroleum refineries, chemical plants, waste disposal and mining companies, manufacturing facilities, other environmental consultants, law firms, public interest groups, individuals, and federal, state and local government agencies.

LOPAT Enterprises, Inc.
640 Mattison Avenue, Suite 200
Asbury Park, NJ 07712   201/776-6710

Lopat's K-20 (patent pending) is a non-volatile, non-corrosive, inorganic colorless and odorless formulation. It has been proven effective on chloradane and PCBs commercially. Laboratory tests prove the product to be totally effective as an incapsultant of asbestos. K-20 was used commercially against PCBs by IT Corporation on five different occasions and in one instance reduced levels from 60 ppm to 0.1 ppm. It has been used effectively against chloradane reducing levels from as high as 1037 cc/sq. ft to non-detectible as per a test done for the Dept. of Agriculture, Pesticide Board, State of Massachusetts. Samples of Lead contaminated soil received from Dallas, TX with readings of 200 ppm were reduced to 0.1 ppm. K-20 is a penatrant, not a surface sealant, reaching depths of anywhere from .75 in. to 2.0 inches in concrete and cinder block. K-20 appears in a forthcoming EPA paper entitled "Practical Methods for Decontaminating Buildings and Structures at EPA Superfund Sites."

**Law Engineering Testing Co./
Law Environmental Services**
1140 Hammond Drive, E-5150
Atlanta, GA 30328   404/396-8000

Law Engineering Testing Company is an internationally established environmental consulting firm. Law's team of environmental professionals is supported by specialized equipment, laboratories and computer capabilities to provide the full range of services necessary to locate, design, permit and operate commercial and industrial facilities.

**MAC Corporation/Saturn Shredder
Division**
201 East Shady Grove Road
Grand Prairie, TX 75050   214/790-7800

MAC Corporation/Saturn Shredder Division—Shear type shredders for shredding of hazardous waste, municipal waste, inplant waste, wood, tires, and various other materials for size reduction.

Marine Pollution Control
8631 West Jefferson Avenue
Detroit, MI 48209   313/849-2333

Marine Pollution Control was one of the first cleanup companies in the United States. We have developed into a mobile, rapid response oriented company, capable of responding to diverse conditions. We are able to handle oil and chemical incidents in land or water environment. We now possess high capacity pumping for emergency response conditions—3000 GPM for light products and capable of pumping coal tar.

Mateson Chemical Corporation
1025 East Montgomery Avenue
Philadelphia, PA 19125   215/423-3200

Specialists in clean air and surface restoration after hazardous materials "accidents" (spills, contamination, etc.). Manufacturers of ecologically safe and test-proven chemicals for decontamination, detoxification, encapsulation, neutralization, adsorption, deodorization, disinfecting and other odor-sorbing products, and we provide "hi-tech" expertise and knowledge in all these areas. We are also distributors for air, particle and gas analyzers, HEPA Air Cleaners, HEPA Vacuums, mobile decontamination stations, hi-pressure washers, sprayers, foggers, etc.

Med-Tox Associates, Inc.
1401 Warner Avenue, Suite A
Tustin, CA 92680   714/669-0620

Med-Tox Associates, Inc. offers services in Industrial Hygiene, Toxicology and Occupational Medicine. Health and safety plans, generic and site specific are developed. Toxicological risk assessments and hazardous materials management are provided, along with training programs. Medical services include the development and implementation of medical standards and medical surveillance programs.

Metcalf & Eddy, Inc.
50 Staniford Street
Boston, MA 02114   617/367-4004

Metcalf & Eddy, a multidisciplinary team of engineers, scientists and health specialists are providing services to governmental and private entities, responsible for hazardous waste management. Metcalf & Eddy has become a leader in hazardous waste management, including hazardous waste site cleanup and waste treatment and disposition projects and technologies. Metcalf & Eddy has conducted site remedial investigations, endangerment assessments and feasibility studies and provided design and construction management services at numerous industrial hazardous waste landfill sites and national priority listed sites (NPL), throughout the United States and abroad. Our hazardous waste specialists—toxicologists, chemists, chemical and environmental engineers, soil scientists, hydrogeologists, surface water, air and groundwater modelers, and health and safety experts—all give Metcalf & Eddy the ability to conduct hazardous

waste site studies, and to design and implement remedial clean-up activities which would mitigate any waste site threats to public health, welfare and the environment. Our specialty includes appropriate technology evaluations, health and safety planning, remedial design, construction management, environmental impact assessments, endangerment assessment, feasibility studies, remedial investigations and source reduction engineering. For more information contact: Donald P. Brown, 617/367-4395.

NUS Corporation
910 Klopper Road
Gaithersburg, MD 20878   301/258-1299

The Site Remediation and Construction Division of NUS combines the scientific and engineering expertise of NUS with the construction and project management capabilities of Brown & Root to provide a single source for hazardous waste site remediation. Services range from remedial investigation/feasibility studies through detailed engineering and construction management. NUS and Brown & Root are well aware of potential liabilities associated with hazardous waste and are dedicated to achieving a sound technical solution to your hazardous waste problem at a reasonable cost. Our single responsibility approach assures client confidentiality through project completion. Feasibility studies are done with ultimate site remediation cost in mind. As a result, site remediation can be accomplished thoroughly and quickly.

National AudioVisual Center
National Archives
Washington, DC 20409   202/763-1850

The National AudioVisual Center—the central source for Federal audiovisual programs—will be showing the in-depth self-teaching program, "Transportation of Hazardous Materials." This 11 unit course will: meet the training requirements of CRF Titles 14 & 49; tell who must comply with the federal regulations; give consequences of non-compliance; identify HM; show proper packaging, transporting and incident reporting requirements. Stop by booth 1804 and examine the complete program as well as many other related programs on display.

National Library of Medicine
8600 Rockville Pike
Bethesda, MD 20209   301/496-1131

The NLM Chemical and Toxicological Files are an online, interactive retrieval service in toxicology. They include CHEMLINE (Chemical Dictionary Online), TOXLINE (Toxicology Information Online), RTECS (Registry of Toxic Effects of Chemical Substances), and TDB (Toxicology Data Bank). These files are a part of the Library's Medical Literature Analysis and Retrieval System (MEDLARS).

National Seal Company
600 North First Bank Drive
Palatine, IL 60067   312/991-6929

National Seal Company is a leader in the manufacture and installation of geomembranes featuring turnkey projects. With increased emphasis on quality control, especially in hazardous waste containment, NSC has excelled by providing state-of-the-art seaming and installation technology of its membranes. NSC's booth will display seam samples of various geomembranes, highlighting HDPE and XR-5 along with brochures describing our complete line of liners and turnkey capabilities.

National Spill Control School
6300 Ocean Drive
Corpus Christi, TX 78412   512/991-8692

The National Spill Control School provides hazardous materials/hazardous waste training at Corpus Christi and on-site. Courses include: Spill Prevention and Control training for managers and Site Safety Training, a hands-on course, for responders and handlers. On-site courses are developed for the specific needs of the organization.

O.H. Materials Co.
P.O. Box 551
Findlay, OH 45839   419/423-3526

Hazardous materials/substances containment and cleanup; environmental restoration; planned and emergency remedial actions.

ONTECH, Inc.
Post Office Box 171224
Arlington, TX 76003   817/861-5307

ONTECH, Inc. provides industry with computer software and hardware tools to improve environmental management and pollution control operations. ONTECH markets a computer program called IRIS, the Industrial Resources Information System that will: 1. Prepare and print shipping manifests; 2. Maintain permanent storage of shipping and waste disposal information; 3. Catalog transporter and disposal sites; 4. Provide rapid access to safety and emergency information; 5. Print monthly and annual reports of shipping and disposal operations; and 6. Provides a quantitative analysis of waste management operations and costs.

**Oil Recovery Systems, Inc./
Groundwater Technology**
299 Second Avenue
Needham, MA 02194   617/449-5222

Equipment and full services to solve groundwater contamination problems: Scavenger® recovery systems, water table depression pumps, water purification and vapor recovery systems, interface probes and monitoring equipment. Services include: cost-effective recovery design; assessment; emergency response, and risk management. Offices nationwide.

Oxford Liners Inc.
Post Office Box 507
Williamsville, NY 14221   716/688-1321

With increasing costs, many are electing to install polyethylene liners with in-house staff. Having this in mind, Oxford Liners, Inc., has available technical and equipment assistance for expert quality liner systems. Our technical staff and a strong compliment of installation equipment permits rapid installation by anyone, anywhere in North America. Call us for a representative in your area. See our welding technology continuously demonstrated at Booth 707.

PB-KBB Inc.
P.O. Box 19672
Houston, TX 77224   713/496-5590

Subsurface engineers specializing in the underground disposal of hazardous waste—especially in bedded or domal salt formations. Company capabilities include permitting, design, construction management and facility operation.

Packaging Research and Design Corporation
12717 Pecos Ave.
Greenwell Springs, LA 70739   504/261-1474

Packaging Research and Design Corporation specializes in custom designing and manufacturing disposal plastic bags for transporting hazardous wastes. Our patented bag liners are offered in many different sizes for roll-offs, dump trailers, vans and luggers.

Penberthy Electromelt International, Inc.
631 South 96th St.
Seattle, WA 98108   206/762-4244

The Penberthy Pyro-ConverterTM is a tunnel incinerator having a pool of molten glass covering the bottom. The molten glass, heated electrically, constantly maintains required destruction temperature no matter what is being burned (oil, solvents, carbon tet, PCB, water, mud, dirt). Inorganic material dissolves in the glass and becomes a delisted material.

Perma-Pipe
7720 Lehigh Avenue
Niles, IL 60648   312/966-2150

Perma-Pipe offers Double-Pipe/PermAlert II systems designed exclusively for the safe transportation of hazardous fluids. Featuring Secondary Containment and Leak Detection, they will: **contain** hazardous fluid leakage, preventing it from entering the environment; **protect** service pipes from corrosive external conditions, **detect** leaks and provide audio/visual alarms; **locate** leaks immediately displaying and recording location and time of occurrence. Double-Pipe is one sure way to protect the environment, public health *and* your bottom line.

Photovac Incorporated
Unit 2, 134 Doncaster Avenue
Thornhill, Ontario
L3T 1L3 Canada   416/881-8225

Photovac's Model 10A10 Portable GC has become the tool of choice in many hazardous waste site investigations. Allows rapid screening of air, groundwater and soil for trace volatiles; these include virtually all chlorinated solvents. Photovac's new TIP product provides a very portable, low cost, photoionization scoping tool for preliminary investigations.

Pollution Abatement Consultants & Services
Div. of Wheaton Ind.
1301 N. 10th St.
Millville, NJ 08332   609/825-1400

PACS will have on display hazardous material shipping containers and packages; samplers for waste streams, ponds, lagoons, sludges & soils, drums, etc.; safety coated glass sample containers, general solvent analysis/solvent recovery units, lab aids to meet EPA & ASTM standards, and portable instruments for field use.

Poly-America, Inc.
2000 West Marshall Drive
Grand Prairie, TX 75051   817/640-0640
                                                   800/527-3322

Poly-Flex Geomembranes—many advantages include: resistance to most chemicals; high tensile strength; stress crack resistance; cost effective; widest seamless sheet; ease of installation and easily sealed. Poly-Flex's combination of properties makes it the best liner choice for most applications.

Princeton Aqua Science
789 Jersey Avenue, POB 151
New Brunswick, NJ 08902   201/846-8800

Environmental consulting and testing. Complete environmental laboratory services, plus expert consulting by engineers and scientists on industrial, hazardous waste, aquatic, terrestrial and environmental science projects.

Princeton Testing Laboratories
Post Office Box 3108
Princeton, NJ 08540   609/452-9050

Princeton Testing Laboratory is a leading environmental and material analysis laboratory with five different sections. There is a Spectrographic Laboratory, a Water, Wastewater, & Microbiology Laboratory, an Inorganic Laboratory, an Organic Laboratory, and an Industrial Hygiene & Air Pollution Laboratory. We are NJDEP certified and do analysis on drinking water, potable water, wastewater, sludge, sewage, soil, toxic and hazardous waste for inorganic impurities and contaminants. Also analyzed are environmental samples for trace, toxic or hazardous organic pollutants by GC, HPLC and GC/MS. Commercial products are analyzed for low level concentrations of impurities as well as major constituents, moisture content and contaminants. Our Industrial Hygiene section does ambient air testing and surveys, exhaust gas testing and certification, workplace environment testing for OSHA regulated contaminants and air quality testing of home and office.

QED Environmental Systems, Inc.
1254 N. Main St.
Ann Arbor, MI 48107   313/995-2547

Well Wizard groundwater sampling system. Speeds and improves the collection of groundwater samples from monitoring wells as small as 2-inch diameter and as deep as 230 ft. Each well is equipped with a down well pump which is operated by an easy-to-use portable controller. The Well Wizard is the only dedicated well sampling system and is specifically engineered to ensure sample integrity and reduce field labor.

REACT
P.O. Box 27310
St. Louis, MO 63141   314-569-0991

REACT environmental crisis engineers offers nationwide 24-hour emergency response for hazardous material accidents; environmental crisis engineering for the containment and control of hazardous waste sites; and consulting engineering, including industrial hygiene, RCRA compliance audits, groundwater contamination studies, SPCC plan preparation and chemical hazard analysis and evaluation of potential health effects.

Radian Corporation
P.O. Box 9948
Austin, TX 78766   512/454-4797

Radian Corporation offers turn-key solutions to hazardous waste management problems. A staff of 800+, in strategically located offices throughout the country, provides expertise in: waste characterization, site investigations, sampling and analysis, remedial action feasibility, incinerator testing, permitting support, emergency response planning, and design of remedial action and waste control systems.

Recra Research, Inc.
4248 Ridge Lea Road
Amherst, NY 14226   716/838-6200

Recra Research, Inc. is a chemical, environmental and engineering consulting firm with over 160 personnel in Buffalo, New York and Houston, Texas. Three laboratories (environmental, waste, geotechnical) support the consulting groups. Environmental compliance with state and federal regulations and cost effective waste treatment and management systems are primary services offered to industry.

Resource Analysts, Inc.
Post Office Box 4778
Hampton, NH 03842   603/926-7777

Resource Analysts, Inc. is an environmental chemistry service organization. Specialties include organic, metals, and other inorganic wet chemistry analyses of air, water and solid media in accordance with environmental testing protocol. Consultation is provided for scoping work and interpreting results. Field sampling support service is also available. Laboratory is certified under EPA programs and participates in site investigations, site remediation, industrial operation and government enforcement monitoring.

Resource Technology Services, Inc.
6 Berkeley Rd.
Devon, PA 19333   215/687-4592

Resource Technology Services, Inc. is a hazardous waste management organization involved in the hands-on removal and disposal of chemical wastes. RTS offers a complete range of services including transportation, storage, consulting, personnel training, remedial action and emergency response.

R.E. Wright Associates, Inc.
3240 Schoolhouse Road
Middletown, PA 17057   717/944-5501

R.E. Wright Associates, Inc. is an applied groundwater consulting firm employing professional scientists in the field of hydrogeology, geochemistry, engineering geology, soil science, aquatic biology and geophysics, and providing services to industries

involved in the manufacture, use and disposal of hazardous materials and to State and Federal environmental agencies.

Rexnord
45 Great Valley Parkway
Malvern, PA 19355   215/647-7200

Rexnord Electronic product division will exhibit self-contained breathing apparatus for the FireENTRY, ChemENTRY and HazMatENTRY applications. The BioPak 60 offers full one hour duration, positive pressure and lightweight—24 pounds. EnviroEnergy Technology Center of Rexnord has special experience and services in analytical laboratory bench tests and pilot physical chemical and biological systems and operations including mobile vans. Full size, scaleup and implementation including Spill Prevention Control and Containment.

Roy F. Weston, Inc.
Designers/Consultants
Weston Way
West Chester, PA 19380   215/692-3030
                                                   ext. 257

Roy F. Weston, Inc. is a leader in hazardous waste and remedial action engineering providing comprehensive environmental management services in the areas of: risk assessments, compliance reviews/audits, permitting, site upgrading/mitigation/cleanup, emergency response, air quality monitoring and real-time environmental monitoring.

SCS Engineers
4014 Long Beach Blvd.
Long Beach, CA 90807-2687   213/426-9544

SCS Engineers specializes in solid and hazardous waste management issues. Services offered by the firm include: selection and design of remedial measures; preparation of closure plans; preparation of spill response plans; and permitting assistance. The firm is experienced in toxic air emission control and treatment. Founded in 1970, SCS maintains offices in Long Beach, CA; Reston, VA; Bellevue, WA; and Covington, KY.

SIJAL Inc.
205 Roesch Avenue
Oreland, PA 19075   215/572-0216

Protective clothing including Chemtex coveralls and three-piece suits specially formulated for chemical resistance.

SKC, Inc.
395 Valley View Road
Eighty Four, PA 15330   412/941-9701

SKC manufactures instruments for chemical hazard detection and air sampling. Complete line of air sampling pumps and tubes; calibration equipment; asbestos test kit and collecting medium and accessories, i.e., filters, impingers, sample bags. Passive dosimeters include: organic vapors, liquid and specific badges for mercury and phosgene. New products include: portable colorimetric tape monitors for phosgene, hydrazines and isocyanates.

SMC Martin Inc.
900 W. Valley Forge Rd.
P.O. Box 859
Valley Forge, PA 19482   215/265-2700

SMC Martin Inc., over the past two decades, has imaginatively combined consulting services in the fields of geology, hydrogeology, geochemistry, soils, civil engineering, planning and surveying. Our professionals regularly provide expertise in groundwater protection and remediation, water resources development, mining, foundations and environmental assessment in a cost effective manner.

SRW Associates, Inc.
2793 Noblestown Road
Pittsburgh, PA 15205   412/921-0321

SRW Associates, Inc. is a civil, geotechnical and environmental engineering firm specializing in waste

management and waste engineering for industry and government. Services include: design; permitting; groundwater monitoring; planning; remedial investigation; feasibility studies; site closure; soil laboratory testing; liner compatibility testing, and Part B applications.

Seaman Corporation
102 N. Washington St.
Millersburg, OH 44654   216/674-0040

Seaman Corporation is a manufacturer of high quality membrane lining products; products which are used for hazardous waste containment including landfill and liquid containment.

Sentex Sensing Technology, Inc.
553 Broad Avenue
Ridgefield, NJ 07657   201/945-3694

Services: Identification and monitoring of known and unknown hazardous vapors at various sites through G.C.M.S. analysis and computerized portable gas chromatograph. Devices: Computerized portable gas chromatograph; multi-point chromatograph system.

Sevenson Construction Corporation
Hazardous Waste Division
2749 Lockport Road
Niagara Falls, NY 14302   716/284-0431

Sevenson Construction Corporation operates a division specializing in a wide variety of remedial construction techniques at hazardous waste sites. Services performed include the removal, treatment and disposal of hazardous materials, earthwork, concrete work, secured on-site and off-site containment facilities, lagoon solidification, slurry walls, leachate and waste water treatment facilities

Shepherd Engineering Testing Co., Inc.
2720 South Classen
Norman, OK 73071   405/364-2900

Shepherd Engineering Testing Co., Inc. is a full service geotechnical engineering and construction materials testing company. The firm specializes in geotechnical drilling, monitor wells, piezometer installation, and mineral exploration drilling activities with large emphasis on hazardous materials sites.

Shirco, Inc.
1195 Empire Central
Dallas, TX 75247   214/630-7511

Shirco, Inc. incineration systems featuring the use of InfraRed heating and conveyor belt transport of waste materials through an efficiently insulated modularly constructed waste disposal system. Since no fossil fuel is required, the reduced gas flow is economically treated to meet requisite emission standards. Systems are excellent for intermittent operation and have transportable capability. Shirco Portable Pilot Test Unit available for on-site testing at your facility.

Slurry Systems/American
Foundation, Inc.
Post Office Box 360
Morrisville, NC 27560   919/467-7896
                               215/678-7176

Vibrated Beam Slurry Cut-Off Wall Systems—for chemical/hazardous waste and leachate control, water conservation and construction dewatering. Our specially formulated slurries impede water pollutants to the specified "K-factor" of impermeability. We Cut Off Problems!

SolidTek Systems, Inc.
5371 Cook Rd.
P.O. Box 888
Morrow, GA 30260   404/361-6181

Full spectrum of hazardous waste handling, treatment, and disposal services. Custom chemical products and services for solidification, with chemical fixation, for detoxification and delisting. Mobile services for processing, remediation and emergen-

cies. Regional TSDF service. Installed systems for generator locations and POTWs. Advanced secure landfill.

Stablex-Reutter, Inc.
28 Springdale Rd., Bldg. 21
Cherry Hill, NJ 08034   609/751-1122

Stablex-Reutter is a fully integrated environmental analytical laboratory and consulting firm specializing in full priority pollutants and RCRA analyses. S-R has a mobile laboratory and extensive field sampling capabilities for hazardous site evaluations. S-R is fully accredited by USEPA/NJDEP and AIHA. Our instrumentation includes: 4 GC/MS/DS, 6 GC, 3 AA, 1 IC AP, 1 IC.

Stauffer Chemical Company
Nyala Farms Road
Westport, CT 06484   203/222-3000

Stauffer utilizes hazardous wastes for their energy value as NON-CONVENTIONAL FUEL™ in their Sulfuric Acid Regeneration plants.

TECHNOS, Inc.
3333 NW 21st Street
Miami, FL 33142   305/634-4507

TECHNOS is a consulting firm in the applied earth sciences, and specializes in subsurface investigations for: hazardous waste site investigation; mapping landfill leachate; permitting and monitor plans; post-closure long-term monitoring; geotechnical investigations; subsidence and sinkhole evaluation; Karst hydrogeology; search and location of buried containers.

TRC Environmental Consultants, Inc.
Advanced Analytics, Inc.
800 Connecticut Boulevard
East Hartford, CT 06108   203/289-8631

TRC Environmental Consultants specializes in innovative solutions to air, water and hazardous waste pollution problems. Hazardous waste services include determination of contaminant migration, design of remedial actions, waste management engineering, site audits, and real-time monitoring of toxic pollutants using TAGA®, a mobile MS/MS system owned by TRC Advanced Analytics.

Training & Information Services, Inc.
P.O. Box 4769
Silver Spring, MD 20904-0769   301/236-0409

TISI provides course development, training and consultation in the areas of hazardous materials leak and spill control, disposal, medical problems, occupational health, emergency medical services and fire service response, organization and education.

Tria
(Elson T. Killam Associates, Inc.)
P.O. Box 1008
27 Bleeker Street
Millburn, NJ 07041   201/379-3400

Tria is a technical association of Elson T. Killam Associates, Inc., Leggette, Brashears & Graham, and GEOMET Technologies. The Tria group specializes in comprehensive hazardous waste management including site, inspection, hydrogeology, health and safety, site engineering and remedial design.

U.S. Army Corps of Engineers
P.O. Box 103, Downtown Station
Omaha, NE 68101   402/221-7317

The U.S. Army Corps of Engineers and the USEPA have joined forces to clean up Federal Lead hazardous waste sites under the Superfund program. The booth will be manned by Corps' personnel to assist architect-engineer firms and construction contractors take advantage of work available to them under Superfund through the Corps of Engineers.

U.S. Army Environmental Hygiene
Agency
Aberdeen Proving Ground
Aberdeen, MD 21010   301/671-3651

U.S. Army Environmental Hygiene Agency, Waste Disposal Engineering Division—Army and Department of Defense worldwide support on the management and disposal of hazardous and solid wastes, emergency spill response, soil analysis and groundwater monitoring.

U.S. Environmental Protection Agency
Raritan Depot
Edison, NJ 08837
                              201/321-6677

The USEPA has been actively involved at all levels of hazardous waste management with the investigation, categorization, response activities and remedial actions at hundreds of uncontrolled hazardous waste sites. This display exhibits products for the protection of response personnel, and provides information on current Superfund activities, the latest response equipment for site investigation, research and development for long-term remedial action and USEPA's mobile treatment systems.

U.S. Geological Survey
790 National Center
Reston, VA 22092   703/860-6162

Panels depicting research and products of the U.S. Geological Survey dealing with earth sciences.

Union Pacific System
1416 Dodge Street
Omaha, NE 68179   402/271-4715

Union Pacific System offers a rail alternative to over-the-road handling of hazardous materials and wastes. Trained personnel in hazardous materials and waste handling, well defined incident response procedures, economies in transport costs, and an excellent safety record make this a very attractive option to waste haulers and disposers. Union Pacific will assess your transportation needs and prepare a special logistics and pricing package.

Velsicol Chemical Corporation
2603 Corporate Ave., Suite 100
Memphis, TN 38132   901/345-1788

Velsicol Chemical Corporation is a medium-sized chemical company with 2,000 employees doing business on a worldwide basis. Velsicol's manufacturing plants, located in the United States, Mexico and Brazil, manufacture herbicides, pesticides, rodenticides, intermediate chemicals and plasticizers. A strong and growing company, one key to Velsicol's business success is a corporate philosophy that includes one of the strongest commitments to environmental integrity the chemical industry has ever witnessed.

WAPORA, Inc.
6900 Wisconsin Avenue
Chevy Chase, MD 20815   301/652-9520

WAPORA, Inc. is a leading engineering and environmental consulting firm that has served industry and government for the past 15 years. The firm offers a wide range of experience in the fields of environmental assessment, engineering and policy analysis. Our corporate headquarters are located in Washington, DC, and we maintain regional offices in New York, Philadelphia, Cincinnati, Chicago, Atlanta and Dallas.

Washington Letter on Hazardous Waste
1015 18th St., NW, Suite 200
Washington, DC 20036   202/835-2206

Washington Letter on Hazardous Waste each week reports on federal laws, policies, regulations and court rulings affecting hazardous waste management. It provides concise, independent and informed early warning to both public and private sector managers of current and coming developments that will affect their programs and budgets.

Wastek, Inc.
4700 Packing House Road
Denver, CO 80216   303/296-1765

Wastec, Inc. offers a physical-chemical waste treatment system which has proven to be a commercially viable solution for numerous hazardous/industrial waste water applications. The system is compact, with automated controls which provide intermittent or continuous operation upon waste demand. The effluent from the system can be safety discharged into a municipal sewage system.

Waste Documentation Control, Inc.
P.O. Box 7363
Beaumont, TX 77706   409/839-4495

Waste Documentation and Control writes and markets software for documenting hazardous and other waste shipments. The system prints manifests, reports for public agencies, accounting reports, specific format reports and user defined reports. The entire system is customized to purchaser requirements. The system is available for many single or multi-terminal computers.

Watersaver Company, Inc.
P.O. Box 16465
Denver, CO 80216   303/289-1818

Fabricators of flexible membrane liners, both reinforced and unreinforced. Specializing in PVC, CPE and HYPALON for solid waste landfills, surface impoundments and hazardous waste containment.

Westbay Instruments Ltd.
507 E. Third St.
North Vancouver, B.C.
V7L 1G4 Canada   604/984-4215

Westbay Instruments Ltd—Designers and manufacturers of the MP System, a modular multi-ported groundwater instrumentation system for pressure measurements and groundwater sampling. Components include plastic or stainless steel casing and couplings, inflatable or mechanical packers and pneumatic or electric pressure probes and sampling probes.

Weston Geophysical Corporation
P.O. Box 550
Westboro, MA 01580   617/366-9191

Weston Geophysical, for 27 years, has provided state-of-the-art environmental services in the United States and abroad. Weston's services include: groundwater supply exploration and evaluation; hazardous waste assessment; plume evaluation; and remedial action analysis. Weston is a leader in nondestructive geophysical techniques with supplemental geological capabilities. Weston offers a newly adapted vertical seismic profiling technique which determines hydraulic conductivity of fracture zones in bedrock—crucial to contaminant migration analysis.

Woodward-Clyde Consultants
5120 Butler Pike
Plymouth Meeting, PA 19462   215/825-3000

Woodward-Clyde Consultants is a nationwide professional services firm serving clients for over 30 years. Our practice includes the application of knowledge in engineering, the earth sciences, and the environmental and social sciences. Services offered include: waste management; environmental assessments; geology and hydrogeology; hydrology; site selection studies; oil spill contingency planning; air and water quality studies; geotechnical engineering, and risk and decision analysis.

XonTech
6862 Hayvenhurst Avenue
Van Nuys, CA 91406   818/787-7380

XonTech's GC-810 portable, battery operated, automatic gas chromatograph measures toxic emissions from landfill sites with excellent chromatographic separation. It monitors a wide range of halogenated hydrocarbons of concern. Peaks are automatically integrated and recorded with data on an integral printer. ECD or PID detectors available. Battery operation in field for four hours with built-in rechargeable power pack.

York Laboratories
  Div. YWC, Inc.
200 Monroe Turnpike
Monroe, CT 06468   203/261-4458

Multidisciplined environmental laboratory/engineering consultants. Provide air, water and waste characterization for RCRA criteria, priority and other pollutants. Specializing in gas chromatography/mass spectrometry services with quick turn-around at very competitive prices. Full service environmental engineering including RCRA permitting, hydrogeologic studies, environmental audits and facility design.