

THE 7TH NATIONAL CONFERENCE ON

MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES

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AFFILIATES

Hazardous Materials Control Research Institute
U.S. Environmental Protection Agency
U.S. Army Corps of Engineers
U.S. Geological Survey
Agency for Toxic Substances & Disease Registry
American Society of Civil Engineers
Association of Engineering Geologists
Department of Defense
National Environmental Health Association
National Lime Association
National Solid Waste Management Association

PREFACE

1986 has been a trying year for all of us involved in Superfund activities. At last, however, the waiting is over. Superfund extension was signed into law in October. The extension of CERCLA to 1990 is at a much increased funding level over the previous five-year period of 1980-1985. Much of the increase in these resources will be devoted to expansion of remedial construction projects at NPL sites. During FY 1985, the U.S. EPA began construction work at about 50 sites, compared with 15 sites during FY 1984. Superfund extension requires more than 300 remedial starts in this next five year period.

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 cleanup action will be dealt with first, using the National Contingency Plan for guidance.

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

These *Proceedings* emphasize actual experience obtained during the various stages necessary for remediation of the numerous Superfund sites. These *Proceedings* therefore enable immediate and effective technology transfer for response to other NPL Superfund sites.

ACKNOWLEDGEMENT

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Affiliated organizations include:

Hazardous Materials Control Research Institute U.S. Environmental Protection Agency U.S. Army Corps of Engineers U.S. Geological Survey Agency for Toxic Substances & Disease Registry American Society of Civil Engineers Association of Engineering Geologists Department of Defense National Environmental Health Association National Lime Association National Solid Waste Management Association

The professionals on the Program Review Committee reviewed hundreds of abstracts to develop this informative and interesting program. The Committee was composed of:

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Comprehensive Environmental Assessment And Response Program Confirmation And Evaluation Activities

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ABSTRACT

The U.S. Department of Energy Albuquerque Operations Office (U.S. DOE-AL) initiated the Comprehensive Environmental Assessment and Response Program (CEARP) to identify, evaluate and conduct remedial actions at hazardous waste disposal and contamination sites on the eight nuclear weapons development and production installations under its jurisdiction. The CEARP is being implemented in five phases: Phase 1—Installation Assessment; Phase 2—Confirmation; Phase 3—Technological Assessment; Phase 4—Remedial Action; and Phase 5— Compliance and Verification.

During Phase 1, regulatory compliance was evaluated and disposal/contamination sites were identified. Phase 2 will provide the field data for site characterization, risk assessment, determination of need for corrective action and evaluation of possible remedial actions at hazardous waste sites. Phase 2 is being conducted in two stages: (1) monitoring plan development/reconnaissance sampling and (2) site characterization/remedial investigation. Problem sites across the U.S. DOE-AL complex were prioritized for site characterization and CEARP Phase 2 activities have been initiated.

INTRODUCTION

To fulfill its obligations under CERCLA and RCRA, the U.S. Department of Energy Albuquerque Operations Office (U.S. DOE-AL) initiated a program to identify, evaluate and conduct remedial actions at hazardous waste disposal and contamination sites under its jurisdiction. The Comprehensive Environmental Assessment and Response Program (CEARP) is the U.S. DOE-AL implementation of the CERCLA program outlined for federal facilities by the U.S. EPA. The CEARP is being implemented in five phases: Phase 1-Installation Assessment [regulatory compliance evaluation and site identification, inspection, preliminary assessment and Hazard Ranking System (HRS) evaluation]; Phase 2-Confirmation (site characterization/remedial investigations); Phase 3-Technological Assessment (feasibility studies and remedial action selection); Phase 4-Remedial Action (remedial action design and implementation); and Phase 5-Compliance and Verification (site closeout and monitoring).

The CEARP addresses the eight nuclear weapons installations under DOE-AL. They include three research and development laboratories[Los Alamos National Laboratory (Los Alamos, New Mexico), Sandia National Laboratories-Albuquerque (Albuquerque, New Mexico) and Sandia National Laboratories-Livermore (Livermore, California)] and five production plants [the Kansas City Plant (Kansas City, Missouri), Mound (Miamisburg, Ohio), the Pantex Plant (Amarillo, Texas), the Pinellas Plant (St. Petersburg, Florida) and the Rocky Flats Plant (Golden, Colorado)]. Implementation of the CEARP at the eight installations is being accomplished through the combined efforts of DOE-AL, Los Alamos National Laboratory, DOE Area Offices, the prime contractor at each facility and subcontractors as appropriate.

PHASE 1 FINDINGS

The CEARP Phase 1 Installation Assessment activities are nearing completion. The purpose of Phase 1-Installation Assessment was twofold: (1) to evaluate current operations for compliance with environmental regulations and (2) to identify/evaluate past and present potential hazardous waste disposal sites and contamination areas that may require remedial action under RCRA continuing release provisions or under CERCLA. During the CEARP Phase 1 evaluation, regulatory compliance issues were addressed and referred to U.S. DOE-AL and the installation contractor for resolution. Potential CERCLA/RCRA sites were identified and assigned a positive, negative or uncertain finding, as appropriate, for the following U.S. EPA CERCLA program elements: Federal Facility Site Discovery and Identification Findings (FFSDIF), Preliminary Assessment (PA) and Preliminary Site Inspection (PSI). No CERCLA findings were recorded for sites where past cleanup activities had been documented or current cleanup operations were in progress. Sites where remedial action had already been initiated were categorized as CEARP Phase 4, and sites where past remedial action was well documented will be verified under CEARP Phase 5.

Sites with negative findings (i.e., sites where no significant quantities of hazardous substances remain because of decay/decomposition/chemical reaction or suspected sites where nothing could be found) were documented and eliminated from further evaluation. Sites were assigned an uncertain finding when the status of hazardous substances in the environment could not be determined from the records and insufficient information was available to conduct a Hazard Ranking Study (HRS) evaluation. Sites with uncertain findings will be evaluated further through reconnaissance sampling and followup during the supplementary stages of CEARP Phase 1. Based on the additional data, these sites will be scored using the U.S. EPA HRS and a risk assessment conducted to determine whether the sites should be targeted for CEARP Phase 2 site characterization and potential remedial action (CEARP Phases 3 and 4).

Sites with positive findings under CEARP Phase 1 were scored using the U.S. EPA HRS when sufficient information was available. Sites that received U.S. EPA HRS scores greater than the 28.5 threshold used by the U.S. EPA for inclusion on the National Priorities List (NPL) are identified as CERCLA sites. These sites are being carried forward into CEARP Phase 2 for confirmation (site characterization/remedial investigation) and are being evaluated in accordance with the U.S. EPA CERCLA guidance for Federal facilities. Sites which did not receive U.S. EPA HRS scores greater than 28.5 but which may exceed U.S. DOE clean-up criteria, potentially present an environmental risk or pose regulatory compliance concerns also are being carried forward for site characterization and risk assessment under CEARP Phase 2. Sites with positive findings under CEARP Phase 1, but without sufficient information to be scored using the U.S. EPA HRS, are being further studied in the supplemental portion of CEARP Phase 1 to obtain the additional information needed for scoring.

During the CEARP Phase 1 activities conducted to date, more than 500 potential sites have been screened at the eight facilities. These sites range from employees' recollections of minor spills of oil or hazardous materials to documented waste disposal sites containing hazardous chemical and/or radioactive wastes. All reported sites were listed and investigated. Many of the sites identified do not contain significant amounts of hazardous materials. However, all the sites with positive or uncertain findings, as indicated above, have been targeted for further evaluation. Approximately 130 sites have been or will be carried forward into CEARP Phase 2 for site characterization/remedial investigation. Another 200 of these sites are being further evaluated under the supplementary CEARP Phase 1 reconnaissance and followup program to document the present conditions and determine if site characterization is appropriate.

Scoring of the potential CERCLA/RCRA sites using the U.S. EPA HRS indicated that only one of the U.S. DOE-AL installations, the Rocky Flats Plant, has any sites that exceed the U.S. EPA threshold for listing on the NPL. The sites with high scores at the Rocky Flats Plant have received priority consideration and are being evaluated in accordance with U.S. EPA CERCLA requirements.

Although a variety of sites were scored at the other seven installations, the scores received were significantly lower than the 28.5 NPL threshold. Preliminary evaluation of the sites with low scores has indicated that the U.S. EPA HRS is not adequate to determine the long-term potential for migration of contaminants from these sites and, hence, the need for remedial action. In addition, the scores cannot be used to rank relative priorities because the U.S. EPA HRS does not readily account for the differences in transport potential from the diverse environments encountered in the CEARP investigations. Therefore, the U.S. EPA HRS scores have been used in the CEARP only to indicate a relative comparison between CEARP sites and other U.S. EPA high priority NPL sites.

Table 1 lists the U.S. DOE-AL installations and provides a brief summary of the principal functions, some of the special hazardous materials routinely handled and materials which potentially may be found in the environment. Because of the unique testing conducted at both Sandia National Laboratories-Albuquerque and Los Alamos National Laboratory since the early days of nuclear weapons development, these installations contain a significant number of potentially contaminated firing sites (sites for test firing high-explosive configurations containing various heavy metals) in addition to waste disposal sites. The CEARP Phase 1 evaluation identified many of these sites for further site characterization. Migration potential and risk evaluations from these sites will be included as an important part of the successive CEARP activities.

PHASE 2 PURPOSE AND SCOPE

The CEARP Phase 2 Confirmation activities provide the field data for site characterization, risk assessment, determination of the need for corrective action and evaluation of possible remedial actions at hazardous waste sites. To accomplish this, the sites are characterized in sufficient detail to: (1) determine the areal and vertical extent of contamination, (2) make a qualitative and quantitative determination of the spatial distribution of contaminants within the site, (3) evaluate the potential for migration of contaminants from the site and (4) assess the risks to humans and the environment.

CEARP Phase 2 is being conducted in two steps: Phase 2A-Monitoring Plan development (i.e., reconnaissance sampling and development of plans for remedial investigations) and Phase 2B-Site Characterization (remedial investigations). Because the data collected during the CEARP Phase 2 site characterization activities will provide the necessary information for conducting the Phase 3 technology assessment (feasibility study), the CEARP Phase 2 site characterizations are being conducted in tandem with the CEARP Phase 3 technological assessments/feasibility studies.

PHASE 2 IMPLEMENTATION

Phase 2A-Monitoring Plans

Development of CEARP Phase 2A reconnaissance sampling and monitoring plans was initiated for the U.S. DOE-AL facilities during 1986. A three-tiered approach is being used in the development of the monitoring plans: (1) the CEARP Generic Monitoring Plan (CGMP), (2) Installation Generic Monitoring Plans (IGMP) and (3) Site-Specific Monitoring Plans (SSMP). The CGMP provides the generic policies and procedures that are being implemented at all the installations and at all the sites. An IGMP is being prepared for each U.S. DOE-AL installation. Each IGMP identifies sites targeted for remedial investigation at this time and provides installation-specific information that is being or will be incorporated into each of the SSMPs. An SSMP will be prepared for each planned remedial investigation. Individual remedial investigations are being conducted for individual sites or groupings of sites (combined because of proximity or similarities). Each tier of plans consists of a synopsis (introduction), sampling plan, health and safety plan, technical data management plan and quality assurance/quality control plan.

At the SSMP level, the synopsis describes the known characteristics of the site, identifies possible remedial actions and specifies the data needed to evaluate the migration potential and environmental risks; finally it allows one to select one of the alternative remedial actions. The SSMP sampling plan is used to guide the site characterization process to: (1) define the objectives of the investigation; (2) select a sampling approach; (3) identify sampling locations and the number and types of samples; (4) specify sample collection and analytical methods; and (5) define sampling logistics. The SSMP health and safety plans identify hazards and evaluate personnel risks, stipulate personnel protection requirements and provide contingency plans for dealing with specified emergencies. The SSMP technical data management plans provide procedures for storing, manipulating, retrieving and archiving data collected during the site characterization. The SSMP quality assurance/quality control plans provide a description of the procedures for systematic control and crosschecking of all aspects of the data collection process, including the adequacy of the measurement or sampling program as well as laboratory controls addressing analytical accuracy and precision. Together the plans provide relevant information similar to that provided in the Remedial Investigation Plans used by the U.S. EPA. The plans are being submitted to the U.S. EPA and to the state authorities for review and comment before beginning the CEARP Phase 2B individual site characterization activities.

Phase 2A—Reconnaissance Sampling

Reconnaissance sampling is being conducted as part of the CEARP Phase 2A SSMP development process. The reconnaissance sampling program provides preliminary data as appropriate for better SSMP sampling plans design. The degree of reconnaissance sampling conducted depends on the information available for a specific site and may include followup site inspections, geophysical surveys, direct measurements of radiation or contamination levels and/or collection of samples for analysis.

The reconnaissance sampling program provides useful input to the development of the SSMPs and site characterization/remedial investigation activities. Because of limited historical records for many of the sites, followup site inspections, vegetation analysis, geophysical surveys (primarily ground penetrating radar and magnetometer) and aerial photography are being used to locate and map potential subsurface sites. Although site boundaries often cannot be clearly delineated from reconnaissance methods, the areal extent of the sites can be better defined for scoping the site characterization effort.

Because of the nature of the installations being investigated, the CEARP reconnaissance sampling program also provides useful information on the presence of pyrophoric metals (e.g., uranium) and/or high explosives/propellants that will require special consideration during the site characterization effort. In particular, the presence of pyrophorics/high explosives/propellants can limit both the investigation techniques and the equipment used during both reconnaissance and site characterization field investigations. If the site contains high explosives/propellants that could be pressure, shock, spark or electrical impulse sensitive, the site may have to be sampled by remote operations. This sampling could involve conducting geophysical surveys, drilling or coring by remote control from protective bunkers or safe distances. These safety hazards are addressed in the SSMPs and are revised as additional site information is collected.

Phase 2B—Site Characterization

CEARP Phase 2B site characterization activities are being conducted on a priority basis across all U.S. DOE-AL installations. Sites are prioritized according to the following criteria: (1) sites where contamination levels could result in near term exposures to on-site personnel or the public; (2) sites judged to have significant potential for migration of contaminants off-site; or (3) sites that present regulatory concerns.

Major CEARP Phase 2B site characterizations have been initiated at several CEARP sites. Sites selected for initial characterization were chosen because of groundwater contamination problems or potential surface water migration pathways that could potentially result in off-site transport of contaminants. The site

	Tunction	Special Materials	Environmental Contaminent
DOE-AL Wespe	ns Production Pacilities:		
Pinellas	microelectronics	tritium	organic solvents
		high explosives	
Kanana City	macroelectronics	RORO	PCB.
	foams, plastics, metals		organic solvents
Mound	detonators	high explosives	tritium
	tritium componente	tritium	
	hest sources	plutonium	
Rocky	metal fabrication	pistonium	plutonium
Finte		urvajum	umnium
		beryllium	organic solvents
			nitrates.
Pantaz	high explosives	high explosives	high applosives
	fabricating	ordanoce	banam
	nuclear weapons		depleted uranium
	secombly		organic solvents
			oil
DOE-AL Wespo	us Research and Development Pac	ilities:	
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characterization activities are conducted in accordance with the program as outlined in the SSMPs.

Major geohydrological investigations have been initiated to evaluate the potential groundwater migration pathways at the Rocky Flats Plant, Mound, the Kansas City Plant, the Pinellas Plant and Sandia National Laboratories-Livermore. These studies are designed to characterize both the potential sources of contamination and the potential for transport within the interrelated groundwater and surface water systems. The studies include extensive field investigations and hydrological modeling as appropriate to determine compliance with water quality standards and to calculate risks.

CONCLUSIONS

The U.S. DOE-AL CEARP Phase 1 has identified more than 300 waste disposal sites and/or contamination areas within the DOE-AL complex that will require further evaluation for potential environmental risk under CEARP Phase 1 reconnaissance and CEARP Phase 2 site characterization. The CEARP Phase 2 site characterization program is being implemented first at high priority sites and has made substantial progress in the collection of essential source term and environmental transport data. The CEARP has provided and will continue to provide valuable input to the U.S. DOE-AL and other regulatory agencies on environmental risks and the need for remedial actions at federal facilities under U.S. DOE-AL jurisdiction.

Safety Improvement Using Simulation and Advanced Control in Hazardous Waste Incineration

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ABSTRACT

Due to the widely varying rates and characteristics of the waste streams, safe, efficient and stable operation of a hazardous waste incineration facility is a complex and demanding task. This paper describes how a well-conceived computer optimization/advanced control and management information system can be a significant aid to improving plant performance and reliability. Such systems have been employed extensively in the process industries such as oil refining, petrochemicals and chemicals with excellent results in terms of improved profitability and safety. The computer-based management information system is specially suited for this type of facility due to constantly changing feeds and is highly beneficial for inventory control, cost accounting, maintenance scheduling and statutory reporting requirements.

The paper also describes how improvement in worker safety, on-stream time and plant performance can be achieved through an effective training program using dynamic training simulators. With the aid of the simulator, the operator can learn to cope with emergencies and upset conditions in a highly effective manner, minimizing the possibility of equipment damage, personal injury and harmful discharge to the atmosphere.

INTRODUCTION

Hazardous waste incineration plants are rapidly gaining importance due to increased need and their ability to treat a variety of waste streams in a highly effective manner. The waste streams range from waste gas to solid material and can vary considerably in composition as well as rate, depending upon the source and history of the waste. Under these circumstances, it is a challenge for even the best operators to maintain a stable, efficient and risk-free operation.

The application of optimization/advanced control and on-line data base management can significantly improve plant profitability through increased throughput and higher efficiencies. In addition, there are significant benefits in terms of improved plant safety and reliability, since a more precise control is achieved and the effect of disturbances is minimized. The use of real-time dynamic simulators for training allows the operator to become well-versed in coping with emergencies and upsets.

DESCRIPTION OF HAZARDOUS WASTE FACILITY

The design of a hazardous waste incineration facility can vary depending upon the source, type and composition of the waste streams. This paper is based on a typical configuration suitable for the disposal of multiple wastes including gases, liquids, sludges and solids. A block diagram of the facility is shown in Fig. 1.



Block Diagram of a Hazardous Waste Incineration Facility

Liquid feeds and sludges are fed to storage tanks that are reserved for specific types of waste, e.g., high BTU, medium BTU, aqueous or sludge. Solid wastes are stored either in bulk or in drums or fiber packs. The drum feed and bulk feed handling systems are designed to allow feeding into a shredder prior to incineration. The incineration system consists of two units which operate in parallel: (1) a rotary kiln designed to process solids and sludges and (2) a liquid incinerator/afterburner designed to destroy liquid wastes. Aqueous and high BTU wastes can be processed in both the kiln and the incinerator.

Flue gas from the incinerator afterburner enters a quench tower for gas cooling, gross particulate removal and partial acid gas scrubbing. Fresh process water is sprayed in the top zone of the tower for the evaporative cooling of the flue gas. The flue gas from the quench tower is treated in the air pollution control system for final particulate and acid gas removal by means of gas scrubbing. The wastewater from various units is treated in a wastewater treatment system prior to discharge into a receiving system, such as sewer or surface water.

OPTIMIZATION/ADVANCED CONTROL

A hazardous waste incineration facility simultaneously processes a variety of wastes, the characteristics of which vary widely depending upon the type and source. The relative flow rate of each stream is not fixed and must be determined so that there is no buildup of inventory and, at the same time, the design capacity of the equipment is not exceeded. Despite the changing flow rates and waste stream characteristics, it is essential to effectively destroy the hazardous materials. To maximize profitability, it is also necessary to maximize the plant throughput and maintain the operating parameters at optimum levels. This complex task can be accomplished best by incorporating an advanced control and optimization system.

Such systems have been used extensively in the process industry, and their benefits in terms of improved profitability as well as increased safety and reliability have been fully proven. For example, optimization and advanced control have proved to be highly beneficial to the operation of ethylene plants where multiple feeds and products make these units very complex. The objective of an advanced control/optimization system is to formulate an optimal operating plan, reduce this plan to specific instrument set points and maintain operation at these set points. The optimization system to accomplish these goals can be categorized in the following manner:

- Optimization—determination of the optimal operating strategy for the plant, including optimal set points
- Advanced Control—assurance of operation at the optimal set points

Optimization

The rotary kiln and liquid incinerator/afterburner form the core of a hazardous waste incineration facility. These units are closely coupled and the interaction between them must be carefully considered to arrive at the optimum operating parameters. For example, all flue gas from the rotary kiln flows to the liquid incinerator; therefore, the operating capacity of one unit depends upon the other. Similarly, the flow of high BTU waste must be split between the kiln and the incinerator depending upon the available capacity in these units and the plant inventory at a given time.

The raw hazardous waste tankage inventory must be minimized so that the maximum quantity of waste material can be received and processed. A major task of the optimizer is to determine the relative rates of various waste streams to each unit which maximize the plant throughput and, hence, the profitability. These rates must be computed within the constraints of equipment design and maintaining the operating parameters such as incineration temperature, excess air, pressure drop, etc., at values which permit efficient destruction and removal of hazardous components.

Optimization Procedure

The optimizer determines major operating parameters using mathematical models representing the process, thus maximizing the plant profitability by maximizing the plant throughput and minimizing utilities (mainly supplementary fuel), while satisfying all environmental and equipment constraints. The limitations due to system requirements (such as temperatures leaving the rotary kiln, liquid incinerator and afterburner, pressure drops, and excess air) must be built into the model. In addition, the specifications or environmental emissions with respect to NO_x, CO, SO_x and C1⁻ must be satisfied.

The optimizer can be used in both off-line and on-line modes. In the off-line mode, the optimizer runs independent of the plant data base and control system and allows case studies of poltential future operating modes. In the on-line mode, the system optimizes current plant performance using the actual physical state of the equipment and environment.

Advanced Control

After the operating targets are determined by the optimizer, specific set points for all key variables are provided to the control system. The control system maintains the selected variables with a minimum deviation from the set points. The system also seeks to minimize the impact of disturbances. The basic regulatory control consisting of single-loop controllers usually is not sufficient for a plant involving multiple feeds with variable flow rates and characteristics. For such plants, advanced control strategies involving concepts such as feedforward, decoupling, variable PID, cascade, etc., should be utilized. It is also highly beneficial to use mathematical models and/or analyzer data to control a given unit. Examples of advanced control strategies for major areas of the plant follow.

Tank Farm and Waste Preparation

The objective is to maximize the quantity of the wastes that can be received, categorize them based on heating values and ensure that a given waste stream is stored in a tank whose contents are compatible with it. Based on input values for the waste characteristics such as heating values, hazardous component analysis, specific gravity, ash content and viscosity, etc., and by means of appropriate models, the computer-based system determines the following information:

- Destination of the waste stream with respect to the storage tank
- Status of blending of waste material in a given tank
- Specific characteristics of waste material in a given tank
- Best sequence in which to transfer the waste material to the incinerator

Rotary Kiln

The key operating parameters such as feed rates, combustion air and kiln temperature determined by the optimizer become set points for the advanced control system. The fine-tuning of the waste combustion air flow is performed by the final oxygen analyzer. The injection of the solid waste to the kiln is on a batch basis, resulting in pulsation of the heat input which must be appropriately compensated by the high BTU waste or fuel oil flow controller.

The flow of the high BTU waste stream determined by the optimizer to maintain a specific kiln temperature is used as the set point of the flow controller, provided a sufficient quantity of this material is available. If not, then the flow rate of the supplementary fuel oil must be used. An important goal is to minimize the quantity of the supplementary fuel oil.

An appropriate residence time of the feed material must be maintained in the rotary kiln to ensure complete incineration. Based upon the characteristics of the feed material, a residence time is calculated by an algorithm which then determines the kiln speed. This value becomes the set point of the speed control system.

Liquid Incinerator and Afterburner

The main process function of the liquid incinerator is to incinerate the medium BTU waste, waste gas, aqueous waste and high BTU waste. The combined flue gas from the rotary kiln and the liquid incinerator is sent to the afterburner. The entire quantity of waste gas must be incinerated in the incinerator at all times to maintain a constant header pressure. The flow rates of other waste streams are set by the optimizer.

If the required quantity of high BTU waste is not available, the supplementary quantity of fuel oil is calculated by the computer and is used as the set point of the fuel oil controller. The combustion air requirements calculated using the heating values of various streams are used as set points for the combustion air flow controller. An oxygen analyzer in the final stack resets the combustion air flow controller as required.

The control systems for the other parts of the plant are relatively straightforward.

Benefits of Advanced Control/Optimization

The benefits gained from the application of advanced control

and optimization are summarized below.

Capacity

The advanced control and optimization system allows more stable operation and higher rates closer to equipment constraints. Experience from the process industry indicates that an increase in throughput of 5 to 10% can be expected by incorporating advanced control and optimization.

Energy Efficiency

Incorporating advanced control and optimization concepts can significantly reduce the energy consumption of a hazardous waste incineration plant. Although the actual savings are a function of the specific design and operating data, our analysis shows that approximately 5% of energy consumption in the rotary kiln and liquid incinerator can be saved.

Reliability and Safety

The advanced control and optimization concepts allow more precise control of operating variables to minimize the effects of disturbances, thereby improving plant reliability and safety. For example, in the operation of the rotary kiln and liquid incinerator, an accurate control of temperature and excess air is assured at all times and automatically compensates for the characteristics and feed rate of waste streams. This control system minimizes the possibility of explosive mixtures in both the rotary kiln and liquid incinerator, while ensuring complete destruction of hazardous materials.

Advanced control can minimize the number of shutdowns by detecting an upset quickly and taking the appropriate action or by forewarning the operator.

PLANT MANAGEMENT AND INFORMATION SYSTEM

A hazardous waste incineration facility is associated with extensive statutory reporting requirements which make it essential to monitor and record a substantial amount of operating data. In addition, there are internal reporting requirements with respect to feed rates, energy usage, maintenance, inventory control and cost accounting. A computer-based plant management and information system can greatly simplify the task of recording and reporting. It also can provide valuable information to management with respect to the causes of equipment malfunction and process upsets, permitting improvement in plant design and operating procedures to enhance plant safety and efficiency.

Federal and state regulations also require that certain operating records be maintained and retained until closure of the facility (20 years or more). This record keeping can be accomplished efficiently by means of the computer-based management information system. Such a system also can include an emergency response program which will provide alarms, information and guidance to plant personnel and public emergency groups in the event of a hazardous occurrence.

TRAINING SIMULATOR

The safe and efficient operation of a modern hazardous waste incineration facility requires highly developed operating skills due to both the complexity and wide range of compositions and flow rates of the feed streams. The use of a training simulator which replicates the dynamic performance of the plant can be a significant aid in developing these skills. Simulators have been used extensively in the airline industry for many years and are now recognized as the ultimate training tool in the process industry.

Most modern hazardous waste incineration facilities exhibit a high degree of interaction, making it essential that the operators become fully conversant with the process and operating procedures. The simulator can assist in a variety of other tasks, such as control system checkout, development of more effective operating procedures and engineering studies. The training of operators prior to plant commissioning ensures smooth and efficient startup with maximum safety and minimum environmental emissions.

Simulator System Objectives

The objective of the simulator is to provide three levels of training which:

- Teach the operator the basic skills necessary to perform control actions and to obtain information through the use of the displays and keyboards
- Familiarize the operator with normal operating values for all the fundamental indication and control loops
- Simulate a set of typical process upsets and equipment malfunctions to provide experience in problem analysis and subsequent corrective action; operators also learn and practice the correct procedure for plant startup and shutdown.

These training objectives are accomplished by a simulation system which integrates hardware, system software, simulation software and process models to realistically simulate a process. The degree of interaction between all components of the simulated plant can be nearly the same as that for all components of the real plant. The complexity of each model component can vary, depending upon its importance to plant operations.

Simulator Components and Configuration

The basic components of a typical simulator system shown in Fig. 2 are:

- Simulation software
- Process models
- Simulation computer
- Traince station
- Instructor station



Figure 2 Simulator Components

Simulation Software

Various types of dynamic simulation techniques are available in the industry. Combustion Engineering Simcon's process models are based on a proprietary GEPURSTM software. GEPURS software is designed to simulate dynamically any process in real time. It is based on a block structure which permits the development of the dynamic process model without the need to record the program or compile after every change.

The interactive and on-line features provided by GEPURS software ease the model development effort significantly. A process consists of many dynamic elements which are physical pieces of process equipment or simple arithmetic equations (such as summation, integration and first order lead/lag). In block-structured software, each dynamic element is represented by a "block" that executes a series of calculations.

Process Model

As described above, the software-based process model replicates the interacting dynamic behavior of the actual plant. Once the plant is started up, the plant engineers can tune and modify the model as required to adhere to physical changes in the plant or to conform to subtle dynamic plant responses that differ from the model.

Simulator Computer

The simulator computer can be 32-bit or 16-bit, depending upon the complexity of the model and various peripherals.

Emulated Trainee Station

The emulated trainee station design depends upon the type of instrumentation used in the actual plant. The emulator replaces the actual operator station with a trainee station similar in appearance to and having the same capabilities as the actual instrumentation. A faceplate type control panel also can be provided depending on the type of instrumentation and training needs of a specific plant.

Instructor Station

The instructor station lets the instructor control the simulation and monitor the status of the simulated process. From this station, the instructor can see all the process information available to the trainee, as well as certain key "internal" process variables. There are also "menu-driven" displays that allow the instructor to load, freeze and snapshot models and to insert malfunctions. The instructor station consists of a color graphic instructor terminal with a function button keyboard, which can produce tabular displays, trend displays and P&I style process overview displays. Displays show real-time data from the model.

Major Benefits of the Training Simulator

- The operators become thoroughly familiar with the operating procedures, substantially reducing the startup time
- On-stream time significantly improves because operators are better equipped to respond to emergencies and process upsets
- The training simulator provides a means to evaluate new control schemes and operating procedures
- The training simulator provides realistic operator training without risking plant upsets or production losses associated with inplant training.

CONCLUSION

The application of advanced control and optimization systems to a hazardous waste incineration facility can greatly enhance plant profitability by improving plant safety, on-stream time and energy efficiency. The use of such a system should be seriously considered at the project planning and design stage so that an appropriate instrumentation system can be selected.

The computer-based management and information system can greatly simplify the task of recording and monitoring the substantial amount of operating data which are needed to meet the federal and state requirements for record-keeping and reporting. The use of a dynamic simulator has significant benefits in terms of reduced startup time, improved plant safety and longer on-stream time.

Deleting Sites from the National Priorities List

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ABSTRACT

The inclusion of sites on the National Priorities List (NPL) is the first step in the Superfund remedial process. This process involves sequential steps including the remedial investigation/feasibility study, Record of Decision, remedial design and remedial action. The process concludes with deleting a site from the NPL, following a determination that the site meets one or more of the deletion criteria described in section 300.66(c)(7) of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

The U.S. EPA has developed procedures for deleting sites from the NPL. These procedures focus on notice and comment at the local and National levels and ensure a sound technical basis for all deletion decisions. The focus of this paper is on the deletion procedures described in the recent draft "Guidance on Deletion of Sites from the NPL." Specifically, it defines the classification of completions for NPL sites, reviews the deletion criteria in section 300.66 of the NCP and the technical evaluation of deletion candidates and describes the overall administrative process.

INTRODUCTION

Under Section 105 of CERCLA, the U.S. EPA maintains a National Priorities List (NPL) of hazardous substance sites. In addition to the inclusion of new sites to the NPL, the Agency intends to delete sites from the list that have been determined to no longer present a significant threat to public health or the environment. The deletion of sites from the NPL will serve to notify the public of Agency actions and should provide an incentive for cleanup response to private parties and public agencies.

The U.S. EPA issued Interim Procedures for Deleting Sites from the NPL on Mar. 27, 1984. As a result of amendments to section 300.66 of the NCP and experience gained from the deletion of 8 sites on Mar. 7, 1986, the U.S. EPA has developed a draft final deletion guidance. This guidance reflects the NCP amendments which no longer preclude the U.S. EPA from returning to a deleted site to expend fund monies. The deletion procedures emphasize notice and comment at the local and National levels and ensure a sound technical basis for all deletion decisions. This paper summarizes the procedures described in the draft "Guidance on Deletion of Sites from the NPL."

DETERMINING SITE COMPLETIONS

The U.S. EPA will identify deletion candidates from those NPL sites (remedial, removal and enforcement) that have first been classified as completions. This classification is based, for the most part, on whether all required response actions (e.g., construction activities) are completed and performance monitoring has commenced. In some situations, completed remedial and enforcement sites will not qualify immediately as deletion candidates and will remain on the NPL until performance standards are met. These sites may be classified separately as long-term responses (LTRs). Regions are responsible for determining whether completed sites qualify as deletion candidates or should be categorized as LTRs until deletion is appropriate. Fig. 1 illustrates this decision process.

Sites classified as completions will receive a "C" status code on the NPL. The necessary stages in the remedial and removal processes before an NPL site may be classified as a completion are illustrated in Fig. 2. Specific requirements for remedial, removal and enforcement sites are discussed below.



Figure 1 Process to Determine Site Disposition



Completion Administrative Process

Remedial Sites

Remedial sites include "no-action" sites and sites where remedial actions are implemented. The latter are considered as completions when all remedial actions, as described in the Record of Decision (ROD), have been completed and performance monitoring has commenced.

"No-action" sites are considered as completions once it is determined that (1) no response is necessary to protect public health and the environment and (2) the no-action ROD has been approved. The determination that the no-action alternative protects public health and the environment will require adequate assessment of all appropriate media (e.g., soils, air, surface water and groundwater) to ascertain that levels are safe for each exposure pathway.

Removal Sites

For the purpose of this paper, "removal" refers to those NPL sites where a removal action is the only response action necessary to effectively clean up the site. Removal sites are considered as completions once: (1) it is determined that no further removal actions are required, (2) confirmatory sampling determines that taking remedial response action is not appropriate and (3) the ROD for no further action has been approved.

Regional remedial staff are responsible for reviewing On-Scene Coordinator (OSC) final reports to determine if remedial response is needed. This review process will require an analysis of all confirmatory sampling to ascertain whether there is a significant threat to public health or the environment. Evaluations should focus on identifying any limitations in the data and whether the data are sufficient to justify a decision that no significant threat to human health or the environment exists and that no further response actions are necessary.

Enforcement Sites

Enforcement sites include Federal and state enforcement-led sites and Federal facility sites which are classified as completions as defined above for remedial and removal sites. These sites also are required to have approved decision documents detailing how cleanup criteria have been met in order to qualify as a completion (i.e., Enforcement Decision Documents (EDDs) for Federalled enforcement sites and Compliance Agreements, or an equivalent, for Federal facilities and State enforcement-led sites).

LONG-TERM RESPONSES

Some remedial and enforcement sites that are classified as completions will not immediately qualify as deletions and will remain on the NPL until performance standards are met. These sites may be classified separately as LTRs. U.S. EPA Regions are responsible for designating sites as LTRs prior to the promulgation of a final NPL rulemaking.

Examples of situations where completed sites may be placed in the LTR category include:

- Long-term remedial action is required, such as groundwater extraction and treatment
- Institutional controls necessary for the effective performance of the remedy or protection of public health have not been put in place by local and/or State governments
- The effectiveness of the remedial action has not been verified

NPL DELETION CRITERIA

Section 300.66(c)(7) of the NCP (50FR 47912) provides that sites may be deleted from, or recategorized on, the NPL when "no further response is appropriate." To delete a site, the Regions and Headquarters must determine whether one or more of the following deletion criteria have been met:

• The U.S. EPA, in consultation with the state, has determined that responsible or other parties have implemented all appropriate response actions required.

- All appropriate Fund-financed response under CERCLA has been implemented, and the U.S. EPA, in consultation with the state, has determined that no further response by responsible parties is appropriate.
- Based on a remedial investigation, the U.S. EPA, in consultation with the state, has determined that the release poses no significant threat to public health or the environment and remedial measures are not appropriate.

These deletion criteria are not intended to establish specific monitoring requirements or performance criteria. Site-specific requirements and criteria are incorporated into the design of response actions for each site as post-closure monitoring, confirmatory sampling and operation and maintenance plans.

Deletion of a site from the NPL does not preclude eligibility for subsequent Fund-financed or Potentially Responsible Party (PRP) actions. Section 300.66(c)(8) of the NCP states that Fundfinanced response actions may be taken at sites that have been deleted from the NPL if future conditions warrant such actions. Depending upon releases from liability contained in the consent decree or administrative order, future enforcement action may be taken if necessary.

TECHNICAL EVALUATION OF DELETION CANDIDATES

In order to determine that one or more of the deletion criteria have been met, the Region will perform a technical evaluation of the data generated from performance monitoring and/or confirmatory sampling. These data must demonstrate that the remedy has achieved the cleanup levels chosen for the site as defined in the ROD, EDD or an equivalent decision document. If the no action alternative is selected, data must confirm that the site poses no significant threat to public health or the environment.

More specifically, technical documentation and data for any site must demonstrate that:

- Groundwater is safe to drink and does not pose a threat to environmental receptors or that controls/treatment achieve the degree of cleanup or protection specified in the ROD/EDD and outlined in the groundwater protection strategy for the classification or affected groundwater
- Soils/waste do not affect the achievement of cleanup objectives specified for other environmental media (e.g., groundwater, surface water or air) and that the direct contact threat is at an acceptable risk
- Air emissions are protective of public health and the environment as defined in section 112 of the Clean Air Act (CAA) and the 1977 CAA amendments for primary and secondary major criteria pollutants
- O&M specified for a site is guaranteed by the state or PRP and is sufficient to maintain the effectiveness of the source control remedy and performance objectives
- Institutional controls necessary to protect public health and the environment and for the effective performance of the remedy are in place

For pollutants without established standards, an assessment of risk will be necessary to determine that exposure levels are protective of public health and the environment (i.e., range 10^{-4} to 10^{-7}).

Prior to deleting a site, the U.S. EPA will make a determination that the remedy or the decision that no further response action is appropriate and is protective of public health and the environment. This determination will take into consideration Federal and state environmental requirements which are applicable or relevant and appropriate to CERCLA response actions at the time of deletion. If cleanup standards/criteria have changed since the remedy was chosen, the lead agency or PRP will do a site assessment to evaluate the need for additional response actions to meet current standards/criteria.

DELETION ADMINISTRATIVE PROCESS

The administrative process for deleting sites from the NPL is illustrated in Fig. 3 and summarized below.

Initiation of the Process

Regions will initiate the deletion process by consulting with states and obtaining their concurrence on the Agency's intent to delete a site. In some cases, the state or PRP may initiate this process by specifically requesting the deletion of a site. Following state concurrence, Regional staff will brief the Regional Administrator (RA) on the status of cleanup response at the site and obtain the RA's approval to proceed with deletion.





The Regions will prepare a deletion docket containing all pertinent information supporting the Region's deletion recommendation. A complete deletion docket will be maintained in the appropriate Regional public docket and local repositories before the Region publishes the Notice of Intent to Delete.

Public Notices and Response to Comments

Once the deletion docket has been established, the Region will prepare a *Federal Register* notice of the Agency's intent to delete a site and will provide U.S. EPA Headquarters with a copy for review and comment. This National notice will describe the Agency's deletion criteria and provide: (1) the location of the Regional dockets, (2) request for public comments for a 30-day period and (3) description of site history, response actions, cleanup standards and criteria and other site-specific information pertinent to the deletion of the site.

The Region also will prepare the local Notice of Intent to Delete. This statement is distributed to community, state and local officials; appropriate Federal agencies; enforcement personnel from the Office of Regional Counsel (ORC); and any local repositories. In addition, the ORC will inform the State Attorney General and other interested agencies of the possible deletion. The local notice will provide the same information contained in the National notice.

Regions are responsible for preparing responsiveness summaries of local and National comments including the Agency's responses to the comments. Headquarters will assist the Regions in preparing responses to those comments which address issues of National concern. Regions will send copies of comments received in response to the local and National Notice of Intent to Headquarters.

The responsiveness summary also may provide justification for proceeding with the deletion if public comments indicate strong disagreement with the recommendation. If significant comments are received, Regions may elect to delay publication of the deletion until the issue(s) are resolved. Regions will include a copy of the responsiveness summary, approved by the RA, in the Regional public docket.

Publication of Deletions

Regions will prepare a draft *Federal Register* notice to announce the deletion of sites from the NPL which will include a summary of the comments received from the Notices of Intent to Delete (local and National) and the Agency's responses. Regions will submit the Notice of Deletion and Action Memorandum to the Assistant Administrator, Office of Solid Waste and Emergency Response (AA, OSWER) for concurrence and publication. Any supporting documents relating to specific Agency responses to public comments also will be submitted. The AA, OSWER will publish the Notice of Deletion in the Federal Register, and final NPL rulemakings that occur after its publication will reflect the deleted sites.

CONCLUSIONS

The U.S. EPA's final deletion procedures, by establishing specific requirements for the technical review and evaluation for all response actions at NPL sites, will ensure a sound technical basis for all deletion decisions. Because the deletion of sites from the NPL will become increasingly important as more remedial actions are completed, public agencies and private parties should be familiar with the criteria, documentation and administrative procedures described in the deletion guidance in order to effectively participate in the deletion process.

Implementation of Superfund: Community Right-to-Know

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ABSTRACT

The tragedy of Bhopal focussed the attention of the American government, citizens and industry, on the fact that there is a real potential for serious, devastating chemical accidents. Congress acted by including requirements in Superfund reauthorization for industry and government to make information available to the public regarding the potential threat from hazardous chemicals in their community. Additionally, requirements are proposed for communities to develop contingency plans to address the possibility of chemical emergencies. The U.S. EPA supports community right-to-know and has worked with Congress to develop this legislation.

To provide guidance to states and local communities in the identification of chemical hazards and preparation for these potential threats, the U.S. EPA announced the Chemical Emergency Preparedness Program (CEPP) in December 1985. CEPP provides guidance, training and technical assistance to states and local communities to help them meet their responsibilities to prepare for and respond to chemical accidents. The guidance assists states and local communities in organizing the community; in eliciting site-specific information from industry to identify potential hazards; and in developing and exercising contingency plans. In order to assist communities in using the CEPP guidance, the U.S. EPA developed criteria and a list of acutely toxic chemicals that would cause serious health effects or death during a short term, high level exposure if released accidentally.

Guidance, training and technical assistance are being provided to state officials and, through states, to local officials to help them identify potential hazards and develop adequate contingency plans. This guidance also will help implement community right-to-know provisions of the Superfund reauthorization. Courses in contingency planning, conducting simulations and developing hazardous materials teams are available through U.S. EPA offices, FEMA Regional offices and the state governments.

These CEPP activities are consistent and complement the community right-to-know and emergency preparedness requirements of Superfund reauthorization. Currently, the U.S. EPA is laying out approaches to implement these provisions and will discuss them at the conference along with the status of the CEPP.

INTRODUCTION

The tragedy in Bhopal, India, an event that occurred halfway around the globe, shocked the United States and the rest of the world into recognizing the enormous potential threat that exists for chemical accidents. Bhopal stimulated an aggressive series of actions to develop and modify programs dealing with the prevention of and response to such accidents.

The message is clear-no matter how good the intent to miti-

gate chemical disasters, to deal with the causes of chemical disasters and to control the conditions surrounding a potential chemical disaster—accidents will still happen and we must be prepared to respond. The U.S. EPA's programs are intended to reduce the possibility of such events and to improve the ability of state and local officials and emergency managers to meet their responsibilities in preparing for and responding to chemical accidents.

Some say that the U.S. EPA's Air Toxics Strategy announced by the Administrator in the summer of 1985 was simply a reaction to Bhopal. All of us know that events such as Bhopal, the release of uranium hexafloride in Gore, Oklahoma, or the radiological release in Chernobyl do not cause us to "start" but rather to renew our existing efforts with greater force and resolve. The Air Toxics Strategy consists of a series of initiatives dealing with routine emissions and a program targeted toward accidental chemical releases. This latter program became known as the Chemical Emergency Preparedness Program (CEPP).

CEPP consists of a series of programs designed to increase community awareness of chemical hazards and to develop or enhance state and local emergency preparedness plans for dealing with chemical accidents.

EXISTING PRE-BHOPAL INITIATIVES

At the outset, it is essential to note that the possibility of a chemical accident in the United States and the need to prepare for such a contingency did not start after Bhopal. There have been preparedness activities in all levels of government—state, local and Federal—as well as in the private sector for many years. It is in full recognition of the always present possibility of accidental chemical releases that several very specific mechanisms have been in place:

- CHEMTREC and the National Response Center
- The National Contingency Plan (NCP), originally designed for oil spills but later expanded to include hazardous materials
- The National Response Team/Regional Response Teams
- Reportable Quantity Provisions in CERCLA

However, it also must be noted that an enormous paradox exists. While there is a continuing and persistent potential for a chemical disaster—after all, large quantities of acutely toxic chemicals are stored, used and transported throughout the nation and the world—nevertheless, a tragic release from a chemical facility has not occurred in this country for many years nor have very many occurred throughout the rest of the world; one can count the major chemical disasters on a single hand—Texas City in 1947; Flixsborough, England in 1974; Seveso, Italy in 1976; Mexico City in 1984 and Bhopal, India in 1984. However, the Bhopal event triggered a great many concerns regarding the possibility of a chemical accident in the minds of the American public. A recent Roper Poll reported that 2 out of 3 Americans believe that a major chemical tragedy will occur in the United States within the next 50 years.

THE CHEMICAL EMERGENCY PREPAREDNESS PROGRAM

While government and industry have approached the problem from different perspectives, the Chemical Manufacturers Association's Community Awareness and Emergency Response (CAER) program and the CEPP both were developed to address specific concerns; concerns expressed by citizens who want to know what they should do to protect themselves; concerns expressed by state and local officials seeking guidance and assistance to revise their programs or initiate new ones where none exist; concerns expressed by industry taking progressive steps to increase safety; and concerns expressed by Congress demanding action.

The CEPP consists of the following:

- Increased federal coordination and technical assistance to state and local governments
- A list of acutely toxic chemicals, criteria and chemical profiles
- A series of guidance documents
- Increased enforcement of existing laws regarding accidental releases

This effort does not involve the reinvention of any new wheels or the development of duplicative mechanisms in regard to preparedness activities for chemical accidents; to the contrary, it builds upon existing mechanisms. To the extent that planning organizations exist in states and local communities, they should be energized and asked to proceed with their programs, to review their priorities and to focus on those issues of greatest concern. If plans exist, communities should review them, exercise them and modify them appropriately. If a planning structure does not exist, the community should establish one which includes all the appropriate members of the community, i.e., first responders, emergency medical officials, chemical engineers, public media, union and industry representatives, etc.

Since the release of the Chemical Emergency Preparedness Program Interim Guidance last December, over 24,000 copies have been provided to states and local communities as well as industry and foreign governments. The CEPP Hotline has handled thousands of calls from state and local officials, industry and interested citizens in its first 9 months.

The U.S. EPA formally requested public scrutiny of its Interim Guidance document and used all comments in the revision of the guidance. Of course, this document also will include appropriate requirements of Title III of the Superfund reauthorization. Most of the comments received dealt with the list of acutely toxic chemicals, the criteria and the quantity determination model. However, major substantive changes to the planning guidance documents were not required. Furthermore, in response to the requests of many state and local officials, several Federal Agencies, which are members of the National Response Team, have agreed to jointly issue unified Federal Guidance for preparedness planning for chemical accidents. This revised guidance will replace several agencies publications, including the popular "FEMA 10" Checklist.

TRAINING AND TECHNICAL ASSISTANCE AVAILABLE

To assist in the implementation of the CEPP, training and technical assistance are being developed for state officials and, through the states, for local officials to help them identify potential chemical hazards and to develop adequate preparedness and response capabilities. Courses in contingency planning, in conducting simulations and exercises and in developing hazardous materials teams are available. These training offerings have been fully coordinated with FEMA, other Federal agencies and the private sector, including the Chemical Manufacturers Association (CMA) and its CAER program.

The NRT and RRTs will be the Federal forum for coordinating these preparedness technical assistance and training activities. While government at all levels must be prepared to provide whatever assistance is required—whether it be training, technical consultation or a question answered by a state or U.S. EPA regional official or the U.S. EPA's national CEPP hotline—effective implementation and the responsibility for dealing with the issues remains local. Therefore, training and technical assistance must be coordinated and developed in response to a local area's specific needs.

OTHER RELATED PREPAREDNESS ACTIVITIES

U.S. EPA Administrator Lee Thomas has directed the Agency to explore issues related to the prevention of chemical releases as part of an overall effort to increase chemical safety and protect the public health and the environment. In this context, the U.S. EPA is continuing to gather information to expand knowledge of the problems associated with accidental releases and their causes as well as to encourage and facilitate prevention activities undertaken by other Federal agencies, states, local governments, private industry and professional organizations.

As part of this effort, the agency has developed a process for gathering detailed information regarding specific accidental releases which also will provide data on preventive measures taken by industry following such events. This effort builds on the information gained through the reportable quantity requirements of CERCLA.

CEPP is designed as a voluntary program. The Congress, however, in Title III of the reauthorization of CERCLA, has legislated Right-To-Know and emergency preparedness provisions which are complementary to and consistent with CEPP but add specific enforcement provisions. In implementing this complex legislation, the agency will build upon the policies, analyses and guidance which have been developed and used in implementing CEPP to the extent possible.

This legislation is geared for implementation at the state and local levels of government and require the establishment of state commissions and local planning committees to assist in the development of emergency preparedness and response plans. This planning requirement is based around those facilities with specified amounts of chemicals that are on the U.S. EPA's list of 402 acutely toxic chemicals. Guidance on contingency planning will be developed by the NRT, and plans may be reviewed and assistance given to local committees by RRTs upon request.

These state commissions, local committees, local fire departments and other first responders will receive information required under the reporting provisions of Title III. These include reporting provisions for emergency notification of chemical emergencies, submission of Material Safety Data Sheets and information regarding inventory of covered chemicals, including location and quantities. In addition to these requirements, information must be submitted by covered facilities to U.S. EPA on emissions inventories. This information will be used as an aid in research and development of regulations and will be computer accessible.

CONCLUSIONS

In conclusion, the CEPP* constitutes an aggressive move toward a comprehensive and cooperative program of response and preparedness involving all levels of government, the private sector and the general public. The program is still in its formative stages, and all material is still characterized as interim. Each of us must do his/her job as we work together to fashion and implement an effective program of local chemical emergency contingency plans.

*If the reader has further questions or would like more information on the CEPP, he/she may call the CEPP Hotline at (800) 535-0202 or in Washington, DC at (202) 479-2449 from Monday through Friday from 8:30-4:30 (EDT).

Improvements in Superfund Site Management

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ABSTRACT

A computerized system was developed in U.S. EPA Region II to assist site managers in planning, monitoring and controlling site schedules. The system was developed using commercially available project management and data base software and existing Region II microcomputers.

The system works through the establishment of individual site schedules by site managers. The site schedules are subsequently combined to provide summary reports to section, branch and regional managers. Benefits of the system include greater consistency of project activity reporting, training of inexperienced site managers and improved capabilities for program managers to allocate limited resources. Future enhancements may include an automated link to CERCLIS, the U.S. EPA Headquarters program management system.

INTRODUCTION

During the summer of 1985 the U.S. EPA's Office of Emergency and Remedial Response (OERR) decided that the Superfund remedial program should be reviewed to determine whether the existing approach was adequate to meet Agency site cleanup goals. Agency and contractor staff with extensive management experience in both Superfund and non-Superfund programs participated in the review.

The evaluation identified several needed improvements to the management and conduct of site activities; a key element that needed attention was improved planning, monitoring and control of site project activities. The evaluation concluded that there was a need throughout the Superfund program for the development of project plans which focused on construction completions, rather than just RI/FS (remedial investigation/feasibility study) completions. The evaluation also identified a need for U.S. EPA site managers to improve their capability to track progress and better anticipate delays and resource conflicts.

Subsequently, Region II staff who had been working on a computerized project planning system offered to lead a pilot project designed to meet the improved project management goals set forth in the OERR study; a second goal of the project was to provide a better means for collecting and disseminating the site management data necessary for good program management. The Region II effort evolved into a site manager based project planning, monitoring and control (PPMC) system.

PROJECT PLANNING, MONITORING AND CONTROL CONCEPT

There are four steps which define the PPMC concept:

- Baseline planning
- Monitoring and reporting
- Analysis
- Management action

Each step constitutes an essential element in the successful completion of a long-term program. The level of detail to which each is applied depends on the complexity of the program and the emphasis placed on the three primary variables:

- Scope
- Schedule
- Cost

The U.S. EPA Superfund program includes important features that require special consideration in developing a PPMC system. First, the Superfund program is still evolving. New sites are identified regularly, and new solutions to toxic waste disposal problems continue to emerge. In addition, the Superfund program has evolved in response to statutory and policy requirements. Thus, the dynamic nature of the program complicates the development of specific scope objectives. The PPMC process, therefore, must be flexible and must be updated on a regular basis to stay in synchronization with the changing requirements.

A second special feature of the Superfund program is the decentralization within the program structure. The sites are located in all states and are managed at the U.S. EPA regional level. Site cleanups primarily are the responsibility of individual U.S. EPA site managers. Further adding to the decentralization of responsibility are the states, the U.S. EPA contractors, the Army Corps of Engineers and private parties participating in various phases of site work. These aspects of the program require that the PPMC system be easy to implement, simple to update and flexible in its application. Users must be free to use as much or little of the system as necessary to accomplish their individual objectives while meeting broader program objectives.

The third important feature of the Superfund program is the annual preparation of program funding levels. Cost goals are based on annual appropriations. Specific site cost targets initially may be "educated guesses," then continuously be refined as site work progresses.

Since a prime objective of the Superfund program is to clean up sites as quickly as possible, the emphasis in the PPMC system should be on the schedule variable within each project. Identification of key milestones, the time required to achieve those milestones and the constraints that could cause deviations from planned schedules are major considerations in the development of the PPMC system.

Finally, there are several basic guidelines which apply to the development of a PPMC system for the Superfund program:

- The goal of the program is to remediate hazardous waste sites; intermediate milestones are only checkpoints of progress toward that goal.
- A plan does not define a precise end point; it merely defines the limits of a pathway in the desired direction.
- The volume of data available makes it easy to become "lost in the numbers" themselves, forgetting what they represent and the level of accuracy to which they were generated.
- The simpler the planning tool and the easier to use, the more it will be used.

The PPMC concept is to develop a plan that forms the baseline by which all activities and performances are measured. The baseline plan needs to encompass all the goals, criteria, limitations and constraints imposed on the site project. It should be the best estimate of the activities and resources necessary to complete the site work available to the site manager at the time the estimate is made. The monitoring process should be designed to report the actual schedule and resource expenditures necessary to accomplish each activity within the project.

The reporting format should match the planning format such that variances can be identified quickly and analyzed by management. Whether the variance is over or under plan, management must answer one key question: have conditions changed such that the initial plan needs to be modified or can procedures be changed to conform activities to the baseline plan at some point in the future? The continuous process of going through these steps contributes significantly to successful completion of the program.

In any program, the data base of planning and monitoring information originates with the smallest unit within the program and is aggregated to provide reports to various levels of management as required. As applied to the Superfund program, the PPMC concept requires the U.S. EPA site manager to develop a baseline site plan representing the best estimate of the activities, resources and schedules required to complete the site work. This information serves as the basis for monitoring site activity and allows early identification of potential schedule and budget problems. The site manager is thus afforded the opportunity to take management action before the problems impede site cleanup progress.

By summing this information for all sites in a region, regional management is able to more accurately forecast program achievements and regional resource needs. At a national level, the information helps paint a more accurate picture of current program status and trends.

This "grass roots" management concept is being implemented in several regions. The discussion in this presentation focuses on the efforts within Region II, where a personal computer based system is being used by site managers to establish baseline site schedules and monitor site activities. Project management software is being used to facilitate schedule updates, and data base software is being used to store schedule data and create reports.

SYSTEM DESCRIPTION

The PPMC system uses generic schedules as the basis for creat-

ing site-specific baseline schedules using commercially available project management software. The baselines then are stored in a regional data base, and a copy of the baseline is used to track actual site work progress. As modifications are made to the baseline copy, it becomes the "actual" schedule or the record of the durations for activities performed at the site. Individual site schedules then can be combined into a variety of different management reports which eventually may be transferred electronically to U.S. EPA Headquarters or other regions. The schedule also may be transmitted directly to CERCLIS to become part of the national Superfund program data base. The PPMC system design is shown schematically in Fig. 1. Key PPMC system elements are discussed below.

Generic and Baseline Schedules

A generic schedule includes a series of over 80 tasks and milestones covering the standard RI/FS, RD (remedial design) and RA (remedial action) activities that occur on a site before it can be considered for deletion from the NPL. Task durations, based on published guidance and input from experienced U.S. EPA and contractor site managers, are chosen to represent average site conditions. The schedule is computerized using project management software which allows tasks to be connected by dependencies so that an increase or decrease in a task duration will show the appropriate impact on the overall schedule. A generic schedule is maintained for each type of site lead or action, currently including Federal-led and state-led site cleanups. Fig. 2 shows the RI/FS segment of a generic schedule for a Federal-led site cleanup.



Figure 1

Project Planning, Monitoring and Control System Design for Region II

The purpose of the generic schedule is to aid the site manager in initially preparing baseline plans. The generic schedule feature is a timesaver for experienced site managers and provides guidance to less experienced site managers. At a minimum, the generic schedule acts as a menu of activities which must be considered in developing a baseline site schedule.

To convert a generic schedule to an actual baseline site schedule, the site manager changes the start and end dates for currently planned activities. As schedules for specific tasks are adjusted, the project management software will automatically adjust the schedules for all subsequent tasks. If inadequate information is available for out-year activities (e.g., RA tasks when the site is at the RI/FS stage), the generic schedules for those tasks will serve as the baseline until some future time when better information will be available.

The site manager establishes the baseline schedule for individual tasks in accordance with a set of standard task and mile-

This is a selective report. All items shown * Notes (1) begins "RI/FS"

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Figure 2 RI/FS Segment of a Generic Schedule for a Federal-Led Site

stone definitions which identify specific task start and end points. The use of standard definitions minimizes misinterpretation of the schedule data in multi-site reports. However, the site manager is not limited to using the pre-defined tasks. He or she may add tasks for his or her own use in tracking site activities or may delete generic tasks that do not apply. The only tasks which are mandatory are approximately 55 tasks chosen by the regional management and 20 chosen by Headquarters. The 20 Headquarters items represent a subset of the 55 regional tasks and are key program milestone and fund obligation points. Since these mandatory tasks are spread over the life of a site cleanup (an average of 5 yr), they represent a minimal reporting burden on the site manager and allow the PPMC system to be used predominantly as a site management tool.

Actual Schedules

Once a baseline schedule is established and stored in the regional data base, the site manager corrects the start and end dates for current tasks and for those future tasks that can be more accurately predicted. Periodically, the site manager obtains an "alarm clock" listing of activities that are late or due. The listing focuses attention on activities that, if not performed on time, will lead to further schedule conflicts.

IMPLEMENTATION

The PPMC system currently is being implemented in Region II through a user review process. The process began with the selection of a group of site managers and section chiefs. The participants' computer knowledge and management experience varied widely. All participants were trained to use the PPMC system and were asked to establish baseline site schedules and subsequently monitor those schedules by submitting updates for inclusion in the regional data base every 2 weeks.

The response of the participants has been very positive. Less experienced project managers have benefitted from the guidance provided by the generic schedules. For example, one site manager noted that, through the process of building baseline schedules, previous commitments to the completion of a Record of Decision (ROD) by the third quarter of FY '86 were based on a schedule much more ambitious than suggested by the generic schedule. Using the generic schedule, the ROD would be signed later than the fourth quarter. From a review of the specific site situation, it was concluded that the generic schedule was, in fact, closer to reality. This example represents a small victory, but it provides a glimpse of the power the system can provide as a management tool. It illustrates how resources can be focused where they are most needed to meet regional program targets if realistic schedule data are developed and used.

Impediments to full-scale implementation in Region II are likely to include a lack of interest (by some) in hands-on use of the microcomputer. This limitation is being circumvented to some extent during the user review by having section or branch designees keep track of several sites at a time. The emerging challenge will be to train site managers that the greatest amount of attention to site management tasks is required when the workload is heaviest. An incentive being tried in Region II is to make attention to management details a part of the annual performance evaluation criteria.

FUTURE GOALS

Future PPMC system work will focus on the development of generic cost information for resource allocation and tracking and increased reporting capabilities. In addition, linkages between the microcomputer systems and CERCLIS are being evaluated; such linkages would help eliminate current reporting burdens. The electronic transfer of data among the U.S. EPA site managers, contractors, Army Corps of Engineers and states is also being investigated to help streamline the reporting/data entry process. One step toward this goal has been a successful effort by the U.S. EPA and Superfund contractors to develop a common set of RI/FS reporting tasks and milestones. Future versions of the Region II generic milestones will reflect the contractor standard tasks.

CONCLUSION

The purpose of the above discussion is not to reveal new conceptual approaches to Superfund site project management or to suggest a specific type of management tool. Instead, the point is to emphasize the substantial benefits which may be gained in program performance through simple, broad-based, "grass roots" improvements in site schedule management. By integrating contractors, states, the Army Corps of Engineers and other program participants in this effort, information transfer can be streamlined and program attention may be focused less on the collection and manipulation of management data and more on the true goal of promoting hazardous waste site cleanups.

Maximizing Cleanup Options And Minimizing Liabilities Under CERCLA

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ABSTRACT

This paper identifies and discusses mechanisms under which companies may maximize cleanup options and minimize liabilities under CERCLA.' First, the paper addresses the purchase and sale of properties that may be contaminated by hazardous substances, and a procedure is provided to help companies ensure they do not unknowingly purchase contaminated properties.

Second, the paper discusses steps site owners and operators may take in response to a proposed or contemplated listing on the National Priorities List (NPL), including specific management procedures for and conditions of government access to privately owned sites.

Third, the paper provides advice to generators, site owners, site operators and transporters regarding participation on committees of Potentially Responsible Parties (PRPs), including pros and cons of PRPs conducting their own Remedial Investigations and Feasibility Studies (RI/FS), based on recent court decisions.

Fourth, the paper discusses special defenses available to generators with regard to shipments and sales of hazardous substances, focusing on CERCLA legislative history and recent judicial opinions.

Fifth, the paper addresses PRP settlement offers, with specific reference to the developing CERCLA Settlement Policy and the recent U.S. EPA policy regarding "how clean is clean."

INTRODUCTION

CERCLA authorizes the federal government to take appropriate cleanup or preventive actions in response to a release or a substantial threat of a release of a hazardous substance into the environment unless the government determines that the cleanup actions will be performed properly by private parties who are liable under the Act.² Government-financed cleanups initially are paid for by a CERCLA-created fund that comprises certain federal appropriations and tax revenues.⁹

Generally, liability for the costs of government cleanup actions under CERCLA may be imposed upon any person who owns or operates the facility from which a release or threatened release emanates, or any person who sends or transports hazardous substances to the facility.⁴ Moreover, any liable party who fails to provide proper removal or remedial action pursuant to a government order may be liable for punitive damages equaling as much as three times the amount of the response costs incurred by the government.³ In addition to cleanup costs and punitive damages, CERCLA imposes liability for "damages for injury to, destruction of, or loss of natural resources."⁴

About half of the states have enacted CERCLA-type statutes; these laws vary considerably from state to state. Some states have created emergency response funds for only certain spills,' while other states have enacted provisions creating hazardous waste funds for immediate or long-term environmental risks.⁴ Such risks may include active⁴ or inactive¹⁰ hazardous waste dump sites, or, more broadly, uncontrolled hazardous substance sites.¹¹ Virtually all of the state statutes provide for at least cleanup cost reimbursement from those parties responsible for the environmental or health risks leading to state abatement actions.

The mammoth liabilities imposed by this array of federal and state statutes have caused companies handling hazardous substances considerable problems. To a large extent, courts have upheld the government's claim that even *de minimus* contributors to hazardous waste sites are jointly and severally liable for site cleanup. There are, however, palpable opportunities for minimizing CERCLA liabilities. This paper presents several such opportunities.

ACQUISITION OF PROPERTY

Owners of property upon which hazardous substances have been deposited are strictly liable for its cleanup.¹² As a result, companies must be careful when purchasing real estate.

It makes good business sense to require an environmental audit of any real property a company wishes to purchase. There are four general categories of information the audit should address.

First, the prospective purchaser should review all environmental regulations affecting the property in question, including applicable standards, guidelines and permits. A full compliance history of the property (and any related facilities) should be outlined. This review should include an identification of all substances released from or to the property that are either hazardous substances (as defined in CERCLA) or are otherwise regulated by environmental, health or safety standards.

Second, a mass balance of all wastes produced at the site should be performed, with specific reference to whether wastes are disposed of on-site or shipped off-site for disposal. For all off-site shipments, compliance with RCRA¹³ must be determined.

Third, all environmental, health and safety enforcement actions, including citizens suits and toxic tort suits, in which the property is involved, or by which the property has been affected, should be identified.

Fourth, the environmental organizational structure and the environmental management practices of the seller should be investigated. Is there an Emergency Response Plan to deal with spills and leaks? Have environmental audits previously been conducted at the property? Are chemical concentrations routinely monitored in the workplace? These are the types of questions that need to be asked regarding organizational structure and management practices.

After conducting the above type of environmental audit of the property, the prospective purchaser will have a good grasp of CERCLA and other environmental liabilities associated with the property and thereby be able to protect itself accordingly. For example, if the property brings with it CERCLA liability, the prospective purchaser may still wish to purchase it subject to a negotiated indemnification agreement. Or, the prospective purchaser may wish to negotiate another transaction involving the property, such as a lease or an easement, thereby lessening the chances that a court will hold it liable as an owner.

SPECIAL RIGHTS OF PROPERTY OWNERS

If a company already owns a property contaminated by hazardous substances, there are a number of ways to maximize cleanup options and minimize liabilities.

The key element is active participation early in the NPL process. The NPL process begins when the U.S. EPA identifies sites and lists them on the Environmental Response and Remedial Information System (ERRIS). Sites listed on ERRIS are subject to Preliminary Assessment and Site Investigation. Data from these assessments and investigations result in quantification of the types of wastes and their effects on the site and its surroundings. The data is processed through the U.S. EPA's Hazard Ranking System. Sites that score higher than 28.5 are proposed by the U.S. EPA for inclusion on the NPL followed by a public comment period and possible final listing.

Owners of potential NPL sites should become involved in the listing process as early as possible. Property owners have certain rights, particularly during the site investigation stage. For example, an owner may set reasonable limitations on the U.S. EPA's entry onto the land. These may include requiring the U.S. EPA to provide the owner with splits of any samples taken on site,¹⁴ copies of reports arising out of site investigation¹⁵ and copies of field investigators' handwritten notes and photographs taken while on-site. Moreover, the owner may require that trade secrets coming to the attention of the investigators during a site visit be treated confidentially.16 Furthermore, employees of the site owner may accompany the U.S. EPA investigators and take notes of their activities. Such notes may be helpful if future questions arise regarding the site investigation. On the other hand, it would be unwise to allow the U.S. EPA investigators to question the site owner's employees without the presence of an attorney. In short, site owners should assert their proprietary rights during a U.S. EPA site investigation. This will result in a better, more complete and fair site investigation.

If, after the site investigation, the U.S. EPA proposes to list the site on the NPL, the site owner has a right to comment on the proposed listing. Generally, proposed NPL listings are subject to a 60-day comment period unless the site is listed under a public health advisory, in which case the comment period is only 30 days.

If a site is listed on the NPL, the listing may be challenged in a judicial action filed in the U.S. Court of Appeals for the District of Columbia Circuit. The challenge must be made no later than 90 days after the site is listed.

PARTICIPATION ON PRP COMMITTEES

The extent to which a PRP should participate on a PRP committee is problematic. Before any decision is made regarding participation, the PRP should thoroughly investigate its involvement with the site in question.

Generally, a PRP who does not own the site (i.e., a generator, a transporter or a former owner) will first become aware of its potential liability when it receives a CERCLA Section 104(e) letter from the U.S. EPA. Among other things, the letter, which usually will be received after the site in question is listed on the NPL, generally indicates that the addressee is being considered a PRP for a particular site and requests the PRP to provide information regarding its relationship to the site.

Immediately upon receipt of the letter, the PRP must conduct a thorough investigation. First, the PRP needs to determine if it sent any wastes to the site in question, and, if so, if any such wastes were CERCLA hazardous substances. If wastes were sent to the site, there are a number of ways of showing they were not hazardous substances. In addition to laboratory results showing that no hazardous substances are present in the waste, the PRP's manufacturing process may be used to show that wastes resulting therefrom could not be hazardous. In addition, constituent parts of the waste may be shown not to contain or react into hazardous substances.

If the wastes sent to the site were hazardous substances, the PRP should determine as accurately as possible the quantity of such hazardous substances it sent to the site. Certain important procedures should be followed by a PRP in determining the extent to which it contributed hazardous wastes to a site.

First, an experienced environmental attorney should be in charge of the investigation. All documents generated during the investigation should be delivered to the attorney to determine whether any of them should be protected under the attorneyclient privilege.

Second, the attorney in charge of the investigation should gather information from three essential sources:

- All documents relating to shipments to the site, including contracts with site operators, shipping orders, bills, permits and memoranda should be collected. From these documents, essential information must be garnered regarding the types and volume of materials sent to the site, fate of the materials at the site and possible transhipments from the site to other sites.
- All insurance policies that may cover the cost of cleaning up the site should be carefully reviewed. If there is possible coverage, notice should be given to the insurance company as soon as possible.
- All employees involved in shipments to the site (including plant personnel) should be interviewed, and their observations should be memorialized.

Armed with information from the above type of investigation, the PRP will not only be in a good position to respond to the CERCLA Section 104(e) letter, but also will be able to effectively evaluate the extent to which it should participate on the PRP Committee.

A PRP who sent small quantities of hazardous substances to the site faces a dilemma. On the one hand, participation in a PRP Committee is time-consuming. On the other hand, the problem of joint and several liability makes at least some form of participation almost mandatory. Generally, a small quantity PRP will want to minimize its presence at PRP meetings but maximize its impact on PRP decision-making. This can be done best by performing all investigations set forth above as early and thoroughly as possible. With detailed information regarding its contribution to the site, the small quantity PRP is in an excellent position to protect its interests among the entire PRP group. One added complication for large companies contributing small amounts of hazardous substances to a site may be the tendency of regulators to look for "deep pockets" as sources of funds for site cleanups.

PRPs who sent larger quantities of wastes to the site, however, will want to take a much more active role in the organization, functions and strategies of the group. These PRPs typically will spend the most time and resources in dealing with the site.

One of the most difficult jobs of the PRPs is to develop an allocation or apportionment scheme for sharing costs of site cleanup. It is at this juncture that most PRP groups have the greatest problems. Antagonisms can be expected to arise between larger quantity and smaller quantity PRPs.

Another problem facing PRPs is the extent to which they should participate in the Remedial Investigation and Feasibility Study (RI/FS) regarding the site. Common wisdom suggests that participation in the RI/FS increases the chances of keeping costs down and improves opportunities for control over the scope of work to be conducted on-site. However, there are disadvantages to heavy participation in the RI/FS, especially if the PRP group itself is to conduct the RI/FS. First, the U.S. EPA maintains authority to supervise the work and to modify it in mid-course. Through the so-called "On-Scene Coordinator," the U.S. EPA may bring the conduct of a remedial investigation to a halt. Second, the U.S. EPA often uses the mechanism of a consent order under CERCLA Section 106 to allow PRPs to conduct the RI/FS. Failure of the PRPs to comply with the terms of the consent order may result in substantial penalties, including the possibility of treble damages. In addition, Section 106 of CERCLA is the Act's "imminent hazard" authority. Entering into a consent order under Section 106 in order to conduct an R1/FS may give the Agency jurisdiction which it otherwise might not have had.

Consequently, the decision regarding the extent to which the PRPs should participate in or conduct the RI/FS must be made on a case-by-case basis after carefully weighing all factors.

SALES OF HAZARDOUS SUBSTANCES

There has been considerable controversy regarding the extent to which a generator may be held liable for the cleanup of a site if, prior to disposal at the site, the generator had sold the material to a third party who, in turn, disposed of it at the site either during or after use. The key language of the Act appears in Section 107(a)(3), which provides that persons who arranged for disposal or treatment at a site from which there is a release are liable for cleanup costs. Arguably, Section 107(a)(3) should not include persons who sold hazardous substances for use by others. Where the vendees are the responsible parties under Section 107(a)(3), not the vendors, who are merely the original generators of the materials.''

This position is supported by the specific language of Section 107(a)(3), which places liability on those who "arrange for disposal" not on generators per se.

Courts addressing the issue have recognized the distinction between "generators" and those who "arrange for disposal." In an important recent case, one court stated that liability under Section 107(a)(3) "is not endless" and is limited to the person who decides how, where and by whom the waste is to be disposed."

The issue of bona fide sales of hazardous substances takes on even greater importance when viewed in the context of the encouragement of recycling and re-use of materials under RCRA.¹⁹ A broad reading of CERCLA Section 107(a)(3) that would hold generators liable for disposal of by-products sold to third parties would act as a disincentive to recycling and reuse via sales, thereby thwarting one of the purposes of RCRA.

In any event, generators who sell by-products or wastes should ensure that their sales contracts expressly provide for indemnification of any possible CERCLA liabilities regarding the ultimate disposal of the materials being sold.

SETTLEMENT OFFERS

A settlement offer by PRPs to the government must carefully evaluate the results of the RI/FS and must take into account the U.S. EPA's CERCLA Settlement Policy and its RCRA/CERCLA Policy regarding "how clean is clean."

The RCRA/CERCLA Policy²⁰ provides that the U.S. EPA will ensure compliance with "applicable or relevant and appropriate" federal environmental statutes in cleanups under CERCLA. State standards may be used if appropriate for specific sites.²¹

The term "applicable," as used in the RCRA/CERCLA Policy, refers to those federal requirements that legally apply. For example, RCRA groundwater protection standards are applicable to the management of hazardous waste in groundwater. Therefore, CERCLA groundwater cleanups will comply with RCRA groundwater protection standards. The term "relevant or appropriate" refers to those standards which are not legally applicable but nonetheless provide useful indicators of appropriate cleanup levels and practices.

One of the important things to keep in mind about the RCRA/ CERCLA Policy is that it will come into focus at the Feasibility Study stage and will drive the decision of the appropriate overall cleanup remedy for the site. It is at that point that requirements regarding which standards are "applicable" and which are "relevant and appropriate" become crucial. This is an additional reason for PRPs to participate in the RI/FS process.

The optimum time for making a settlement offer to the U.S. EPA is as soon as possible after the cleanup remedy is determined. At that point, the PRPs must carefully evaluate the U.S. EPA's Settlement Policy before making any settlement offer to the Agency." The Settlement Policy addresses guidelines for negotiation, criteria for evaluating settlement offers, targets for litigation and other matters.

One of the most important aspects of the Settlement Policy is the Settlement Criteria. Although an exhaustive discussion of the Settlement Criteria is beyond the scope of this paper, a listing of the criteria is instructive:

- · Volume of wastes contributed to the site by each PRP
- Nature of the wastes contributed
- Strength of evidence tracing the wastes at the site to the settling parties
- Ability of the settling parties to pay
- Litigative risks in proceeding to trial
- Public interest considerations
- Precedential value
- Value of obtaining a present sum certain
- Equities and aggravating factors
- Nature of the case that remains after settlement

Even a cursory review of the above ten criteria shows the importance of retaining experienced environmental counsel to conduct settlement negotiations with the U.S. EPA. Many of the criteria are directly related to litigation risks and benefits, and most involve the types of considerations discussed elsewhere in this paper.

In short, the U.S. EPA's Settlement Policy should be used as a guiding document by all who receive Section 104(e) letters. The goal should be to obtain as much information as possible regarding the site and the relative contributions of the various PRPs so that a well-conceived settlement offer can be presented to the Agency in accordance with the Settlement Policy.

CONCLUSIONS

Although CERCLA imposes stringent liabilities on companies, there are a number of ways to maximize cleanup options and minimize liabilities. These options include being cautious in the purchase of real property, taking an early, active part in the NPL listing process, understanding the rights and obligations of PRPs, ensuring that sales of by-products or used materials do not cause unnecessary problems and taking advantage of the directions and criteria set forth in the U.S. EPA's CERCLA Settlement Policy.

REFERENCES

- 1. 42 U.S.C. Sections 9601-9657 (Supp V 1981).
- 2. The term "hazardous substance" is broadly defined in 42 U.S.C. Section 9601 (14) to include a long list of substances regulated under a variety of federal environmental statutes.
- 3. 42 U.S.C. Section 9631.
- 4. 42 U.S.C. Section 9607(a). In addition to releases from facilities, CERCLA also applies to releases from certain vessels. *Id*.
- 5. 42 U.S.C. Section 9607(c)(3).
- 6. 42 U.S.C. Sections 9607(a)(4)(c), 9607(f).
- e.g., Colo. Rev. Stat. Section 29-22-101 to 106 (Supp. 1984); Fla. Stat. Section 403.725(1) (1983); Ky. Rev. Stat. Section 224.876(12)-(13) (Supp. 1984).
- e.g., N.H. Rev. Stat. Ann. Section 147-B:1 to B:11 (Supp. 1983); Okla. Stat. Titl. 63, sections 1-2015 to 2021 (Supp 1984).
- Ill. Rev. Stat. Ch. 111^{1/2}, Section 1022.2 (1982); Mo. Rev. Stat. Section 260.391(1) (Supp. 1982).
- e.g., La. Rev. Stat. Ann. Sections 30:1147-1 to 11149.1 (West Supp. 1985); N.Y. Envtl. Conserv. Law Section 27-1301 to 27-1309 (McKinney 1984 and Supp.).
- 11. Me. Rev. Stat. Ann. Titl. 38 sections 1361-70 (1984).

- 12. New York v. South Shore Realty, 759 F. 2d 1032 (2nd Cir. 1985).
- 13. 42 U.S.C. Sections 6901-6987 (Supp. V 1981).
- 14. 42 U.S.C. Section 9604(e)(1)(B).
- 15. Id.
- 16. 40 C.F.R. Part 2 (1985).
- 17. United States v. A&F Materials Co., 582 F. Supp. 842 (S.D. II1 1984).
- 18. Id. at 845.
- 19. See Reference 13.
- 20. The RCRA/CERCLA Policy is set forth in an internal U.S. EPA memorandum, dated Oct. 2, 1985, from J. Winston Porter to the U.S. EPA Regional Administrators, titled "CERCLA Compliance With Other Statutes."
- 21. CERCLA Section 104 provides that off-site remedial actions must comply with the provisions of RCRA. Regarding compliance with federal environmental standards in other contexts, however, CERCLA is silent.
- 22. Interim Enforcement Policy for Private Party Settlements Under CERCLA. Fed. Reg. 50, Feb. 5, 1985, 5034.

U.S. EPA/State Relationship in CERCLA Enforcement Actions at National Priorities List Sites

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ABSTRACT

In this paper, the authors discuss the U.S. EPA's efforts to more fully involve states in enforcement actions under CERCLA. The authors also address how these efforts should lead to a more coordinated and consistent approach during U.S. EPA and state enforcement actions that seek private party cleanups. Specifically, the authors: (1) outline current thinking behind the need for better coordination and cooperation between the U.S. EPA and states in the CERCLA enforcement program; (2) review specific efforts being implemented to enhance and improve the EPA/ state relationship; and (3) summarize what additional effect CERCLA reauthorization will have on state participation in Federal enforcement actions.

INTRODUCTION

CERCLA, unlike other major environmental statutes such as RCRA, does not impose any statutory requirements on states as a precondition to being involved in or conducting CERCLA enforcement actions. As a result, the U.S. EPA and the states often may proceed independently. The following considerations that are absent from CERCLA further complicate the U.S. EPA/state enforcement relationship.

- CERCLA does not require authorization of state enforcement programs on the basis of minimum legal, technical and resource requirements that states must meet
- CERCLA does not require that state legal provisions and technical procedures used in their enforcement actions be consistent with Federal standards
- CERCLA does not establish mechanisms for Federal involvement in or oversight of state enforcement actions
- CERCLA does not require that states report the progress and results of their enforcement actions

Due to the lack of specific requirements for participation in the CERCLA enforcement program, states vary in their technical, legal and administrative approaches and capabilities. This variation in capabilities may lead to situations where responsible party settlement agreements or cleanups obtained by a state are inconsistent with or do not meet CERCLA requirements. In some cases, it may even lead to problems in deleting a site from the National Priorities List (NPL). Also, situations occur where Federal enforcement actions do not satisfy the desires of a state, such as applying state standards, permitting and other requirements. Furthermore, early identification and resolution of disputes between the U.S. EPA and a state is difficult since no formal mechanism exists for identifying and resolving problems.

In an effort to establish some framework for coordinating their respective enforcement actions, the U.S. EPA and the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) signed a joint policy statement on Oct. 2, 1984.' The policy confirms that absence of a statutory structure for an effective U.S. EPA/state relationship has presented problems in the past, and that issues will continue to arise. However, this mechanism was created to allow the U.S. EPA and the states to deal with those issues in a way that can minimize conflict, enhance respective enforcement efforts and improve the chances for mutually acceptable private party settlement agreements and cleanups.

MAJOR ISSUES AFFECTING THE U.S. EPA/STATE RELATIONSHIP

Based on discussions between U.S. EPA and state representatives, the major issues confronting the U.S. EPA/state relationships were divided into three categories: Coordination; State Enforcement Authorities and Procedures; and Resources.

Coordination

It is established that absence of a comprehensive policy on the U.S. EPA/state relationship has left U.S. EPA Regional Offices and States to determine the level and scope of their relationship on an ad hoc basis. As a result, the level of coordination and cooperation varies among U.S. EPA's Regional offices, as well as among states within the same Region. Without the benefit of guidance from the U.S. EPA to the states on specific issues, differences in the policies and procedures used to conduct state enforcement actions exist among states and between the states and the U.S. EPA.

This lack of coordination and cooperation is compounded by the absence of any formal approach to sharing information between the U.S. EPA and the states on the status of enforcement actions. These problems also have led to occasional delays and conflicts in administrative and judicial enforcement actions. If differences between the U.S. EPA and a state are discovered at all, they may occur late in the enforcement process and beyond the point of meaningful Federal or state participation.

State Enforcement Authorities

and Procedures

Most states rely either on broad state environmental or gen-

eral statutes, or on state hazardous waste legislation enacted prior to CERCLA. State statutes often do not provide the full range of authorities available to the Federal government under CERCLA. Two examples of these authorities are:

- Under Section 106 of CERCLA, fines of up to \$5,000 per day can be applied against any responsible party who willfully violates or fails or refuses to comply with an administrative order issued under the section
- Under Section 107 of CERCLA, the U.S. EPA may seek treble damages from any responsible party who fails without sufficient cause to properly provide response actions under Sections 104 and 106 of the Act.

In the absence of equivalent authority, some states work informally with responsible parties. This informal working relationship can lead to arrangements that are difficult to successfully enforce. State negotiations with responsible parties sometimes are conducted without a time limit. In this instance, negotiations easily can become protracted. Thus, it is often difficult to assess the likelihood of successful state negotiations or whether responsible parties will conduct cleanups consistent with the National Contingency Plan (NCP).

Resources

Funding for state hazardous waste enforcement programs varies widely between states. An ASTSWMO survey conducted in 1983 confirmed that less than adequate resources are generally available at the state level.² Specifically, the survey showed that:

- Anticipated increases in funding among the states still leaves staffing short of what is minimally required
- Limited funding affects the states' ability to employ the necessary disciplines required to conduct their enforcement programs

Without adequate funding, states have been limited in the number of enforcement actions taken and the level of oversight provided during responsible party response actions.

ACTIONS TAKEN TO IMPROVE THE U.S. EPA/STATE RELATIONSHIP

Not all issues confronting the U.S. EPA and the states can be resolved through the U.S. EPA/ASTSWMO joint policy. For example, funding assistance for additional state program personnel is beyond the scope of CERCLA to provide. Also, any inadequacies that may exist in state legal authorities is a matter for states to resolve on an individual basis through their state legislatures. However, the U.S. EPA's Office of Waste Programs Enforcement (OWPE) has begun developing specific guidance to effectively implement many of the recommendations outlined in the U.S. EPA/ASTSWMO joint policy.

Classifying NPL Sites as State-Led Enforcement

CERCLA authorizes two basic approaches to dealing with a hazardous substance release. The government (U.S. EPA or state) may act using monies from the Hazardous Response Trust Fund and subsequently attempt to recover costs from responsible parties. The second approach is to use negotiations and administrative or judicial enforcement actions to encourage or compel responsible parties to finance and manage response actions.

However, current U.S. EPA interim guidance on classifying sites as Fund-financed or enforcement response does not provide for state involvement in determining which approach is most appropriate. Although the U.S. EPA's regional offices should consult with states in making enforcement classifications, the lack of guidance for state involvement has caused inconsistencies in this effort. Cases arise where a Fund-financed or Federal enforcement classification might more properly have been classified as a state enforcement site based on information available or actions taken at the state level. In some cases, this lack of guidance may even cause duplicate or opposing actions to occur at a particular site.

The U.S. EPA/ASTSWMO joint policy helped to correct this problem by establishing a procedure for consultation with states to determine whether an enforcement site should be U.S. EPAor state-led, or "shared-led" where both the U.S. EPA and the state jointly pursue enforcement actions at the site.³ In determining lead responsibility for enforcement sites, the U.S. EPA's regional offices and states are to consider the following factors:

- Past site history, i.e., whether there has been a U.S. EPA or state enforcement activity at the site
- Effectiveness of enforcement actions to date
- Strength of legal evidence to support the U.S. EPA or state action
- Severity of problems at the site
- National significance of legal or technical issues presented by the site
- Availability of U.S. EPA and state legal authorities and adequate personnel and funding resources to enable effective action

If, on the basis of these considerations, a site is classified as state-led enforcement, the state must assure it will:

- Prepare, or have the responsible party prepare, a remedial investigation and feasibility study (RI/FS) and provide for public comment, in accordance with applicable U.S. EPA guidance
- Conduct negotiations with responsible parties formally (e.g., culminating in the issuance of an enforceable order, decree or other enforceable document) and, to the extent practicable, within agreed time limits
- Provide for public comment on settlements, voluntary and negotiated cleanups, and consent orders and decrees in accordance with applicable U.S. EPA guidance
- Pursue and ensure implementation of a remedy that is consistent with the NCP
- Keep the U.S. EPA informed of its activities, including consulting with the U.S. EPA's Regional office when issues arise that do not have clear-cut solutions

If a state in unable to provide the above assurances, the site cannot be classified as a state-led enforcement site. However, the regional office may consider sharing aspects of the response so that state enforcement interests can be directly represented.

This approach to classifying state-led enforcement sites now is being applied consistently across the U.S. EPA's Regional offices. The most recent and beneficial use of the site classification process has occurred with states in the U.S. EPA's Denver Regional office. Until recently, only one site within the Region had a state-led enforcement site classification. A major reason was the difficulty in determining and agreeing whether state laws and standards were adequate to successfully pursue enforcement action consistent with CERCLA requirements. Using the site classification approach outlined in the U.S. EPA/ASTSWMO joint policy as the primary tool, the Denver office and their states are now successfully coordinating and negotiating formal agreements for sites within the Region. Several sites now are classified as state-led enforcement and more are anticipated within the next year. Without the benefit of the classification criteria, the Regional office and states would not have had any common ground or understanding for determining the ability of states to pursue enforcement actions at NPL sites.

Upon CERCLA reauthorization, the U.S. EPA intends to revise the interim draft guidance to properly include state involvement in the site classification process and other areas requiring state participation.

Funding State CERCLA Enforcement Activities

The U.S. EPA's Office of General Counsel (OGC) recently reconsidered an earlier view on funding of state enforcement activities at NPL sites, reflected in a July 20, 1984 opinion. The July 20, 1984 opinion limited assistance to identification of potentially responsible parties (PRPs) and gathering of evidence, RI/FS to support state enforcement actions, and oversight of RI/FS and remedial designs (RD) conducted by PRPs. On Feb. 12, 1986, the original opinion was broadened to allow such activities as: oversight of PRP-conducted remedial actions (RA) and operation and maintenance (O&M); negotiation and litigation to encourage or compel PRPs to initiate response actions; and reporting to the public on PRP response actions. The rationale is that these activities can be defined as a "response" under Section 104(b) of CERCLA and, consequently, are eligible for CERCLA funding.⁴ CERCLA reauthorization also will amend Section 104(d), adding state enforcement to the list of activities that can be funded through cooperative agreements and thereby statutorily allowing what has already been established in the OGC opinions.

Therefore, state CERCLA enforcement activities conducted at NPL sites can be broken down into three major categories.

- State-led RI/FS to support state enforcement actions
- State-led PRP searches, issuance of notice letters, negotiation, administrative action and litigation
- Oversight of RI/FS, RD, RA, and O&M conducted by PRPs at state-led enforcement sites

In response to the U.S. EPA OGC opinions and reauthorization, OWPE has prepared funding guidance for each category of activities. The existing guidance on funding state-led RI/FS outlines the requirements for the first category of activities.' The provisions states must agree to, tasks to be funded and level of funding to be provided for an enforcement-related RI/FS are the same as for any other RI/FS.

For the second category, an interim draft guidance currently is being reviewed by U.S. EPA Headquarters management and soon will be available to the U.S. EPA's regional offices and states.⁶ The intent of funding states for these activities is to successfully secure the greatest number of private party cleanup actions possible. Funding these activities will enable states to devote the time and resources necessary to achieve adequate settlements and judgments. Since Federal funds may be provided, the guidance will require states to follow the Agency's enforcement policies and procedures to the extent possible under state law. This requirement is necessary to ensure that state-led enforcement site cleanups:

- Are consistent with the NCP and applicable U.S. EPA guidance
- Do not require or, if necessary, preclude future Federal enforcement action
- Enable the U.S. EPA to delete the site from the NPL

Cooperative agreement funding for PRP searches, issuance of notice letters, negotiation, administrative action and litigation will be provided only at NPL sites which have been classified as state-led enforcement. Prior to accepting cooperative agreement applications for review and award, the classification criteria outlined above will be applied to the site. Once the classification is made, a state will have to follow the provisions and requirements outlined in the negotiation and litigation funding guidance. The guidance also outlines the tasks to be funded and levels of funding to be provided for these activities.

For the third category of activities, a final oversight funding guidance document has been prepared merging two previous drafts in which oversight of remedial planning (RI/FS and RD) and remedial implementation (RA and O&M) were separately addressed.' Funding for oversight will ensure that states devote adequate time and resources toward analyzing and reviewing the PRP's work. This includes funding for review of PRP work plans and deliverables, field-related oversight, monitoring and sampling and community relations.

Under the final oversight funding guidance, if a state has successfully negotiated an administrative order, consent decree or other enforceable document, then the state has the lead for oversight of the PRP's work and is eligible for CERCLA funding. The state may also, under certain circumstances, undertake various, mutually agreed upon oversight activities at Federal-led sites. These circumstances may include:

- CERCLA, Section 106 settlements with PRPs that are jointly negotiated and signed by the U.S. EPA and the state
- State oversight that can result in a more effective and timely PRP response

The final oversight funding guidance will be issued to the U.S. EPA's Regional offices and states in the near future. The guidance also outlines the provisions states must agree to, tasks to be funded and level of funding to be provided for state oversight.

During the next year, award of cooperative agreements under the oversight guidance and negotiation and litigation guidance will occur on a pilot project basis. The U.S. EPA feels this step is necessary since funding of these activities is a new venture for the U.S. EPA and the states and close oversight initially will be required to ensure consistent national implementation. The longterm budgetary and administrative impacts of this new program effort are only now being determined. There currently are over 150 state-led enforcement site candidates for some type of funding. However, at least ten cooperative agreements are planned during the next year. The U.S. EPA's regional offices already have received and currently are reviewing several applications for awards.

U.S. EPA/State Enforcement Agreements

Where states do not request funding assistance for their enforcement actions, CERCLA does not provide the U.S. EPA specific authority to be informed of and involved in these actions. In an attempt to bridge this information gap, the U.S. EPA/ ASTSWMO joint policy called for the development of U.S. EPA/State Enforcement Agreements (ESEAs) to define their respective roles and responsibilities during CERCLA enforcement actions. As stated in the joint policy, the purpose of the agreements is to ensure that the extent of the U.S. EPA and the state's relationship at each site is fully thought out and documented to prevent misunderstandings at a later time.

Few ESEAs have been prepared since the joint policy was issued. This lack of agreements is partially due to the lack of specific guidance on developing such agreements and the absence of adequate resources in the regions to develop and oversee their implementation. However, a recent decision made by the Assistant Administrator, Office of Solid Waste and Emergency Response (OSWER) to the future U.S. EPA regional office resource requests for state oversight to the existence of formal agreements (cooperative agreements or ESEAs) with states will influence their development in the future. Additionally, provisions for state involvement in Federal enforcement actions outlined in CERCLA reauthorization also will contribute to developing a more formal relationship with states.

OWPE has conducted a survey of existing ESEAs. Information collected from this survey will be used to develop guidance on the content and structure of ESEAs prepared in the future. This will ensure that certain program requirements and responsibilities are consistently applied during CERCLA enforcement actions covered under ESEAs. Pending issuance of detailed guidance on the content of ESEAs, agreements drafted so far have covered many different subject areas, such as:

- Coordinating the U.S. EPA and state activities, from early site planning through enforcement action and site cleanup
- Avoiding duplication of effort between the U.S. EPA and the state
- Preventing lengthy negotiations with responsible parties
- Ensuring that response actions taken at state-led enforcement sites are consistent with the NCP and applicable U.S. EPA guidance
- Providing for smooth transition if a change in site classification is required
- Providing for conflict resolution between the U.S. EPA and the state
- Allowing for review and comment of state and responsible party documents
- Providing a basis for information exchange between the U.S. EPA and the state

Since OWPE has not issued guidance on ESEAs, these existing agreements vary widely in scope and content. Essentially, two types of agreements have emerged: (1) generic agreements addressing all enforcement sites classified as state-led and (2) sitespecific agreements usually addressing a single site (or contiguous sites within a geographical area).

One of the first ESEAs, drafted by the U.S. EPA's New York Regional office and the New York State Department of Environmental Conservation (NYDEC), adopted a comprehensive approach to create a program for all state-led enforcement sites. Provisions of the U.S. EPA/NYDEC agreement tie together the state's enforcement planning activities and the Agency's annual planning process, known as the Superfund Comprehensive Accomplishments Plan. Yearly revisions to the ESEA are based on this coordination of the state and the U.S. EPA's planning activities. The agreement also contains a CERCLA enforcement protocol, provisions for regular management meetings and conflict resolution, and state reporting requirements.

In the South Bay area of San Francisco, several semiconductor firms have contributed to a groundwater contamination problem involving several proposed NPL sites. These firms have agreed to perform a voluntary cleanup. This cluster of sites, sharing close geographic proximity, a considerable overlap of responsible parties and enforcement authorities, is well suited to a consolidated enforcement approach. Confusion arose when the PRPs and the U.S. EPA discovered that cleanup activities came under the jurisdiction of two state agencies. To facilitate efficient and effective enforcement action, both state agencies and the U.S. EPA's San Francisco Regional office developed a site-specific ESEA to clarify their respective authorities, roles and responsibilities.

ESEAS also have been drafted to address legal, technical and administrative details specific to a particular enforcement action. Agreements can be made between the U.S. EPA and the state concerning specific settlement provisions, reporting requirements, technical issues and community relations requirements. Thus, ESEAs can be adapted to deal with special circumstances.

At the present time, ESEAs are not mandatory and are developed at the discretion of the U.S. EPA's regional office and the state. However, because of the Assistant Administrator's decision on regional resource requests for state oversight and new requirements outlined in CERCLA reauthorization, pending guidance on ESEAs may require their use in the future.

Reporting and Exchange of Information

As states become more involved in CERCLA enforcement actions, the flow of information between the U.S. EPA and the states will continue to increase. The Agency will need to ensure that state enforcement actions at priority sites are conducted consistent with U.S. EPA procedures and adequate to allow for deletion from the NPL. The U.S. EPA also will need to determine, in addition to the appropriateness of state enforcement efforts, whether Federal review and participation are necessary. CERCLA reauthorization also will increase the amount of information exchange required in order to have adequate state participation in Federal enforcement actions. The sharing of information needs to be reciprocal in our efforts to seek responsible party cleanups.

The U.S. EPA/ASTSWMO joint policy recognized that sharing information between the U.S. EPA and the states is key to developing a more effective relationship. The policy, therefore, encouraged states to keep the U.S. EPA informed of their activities, including consulting with regional offices when issues arise that do not have clear-cut solutions.

Until recently, the U.S. EPA had very little information describing the status of enforcement actions at state-led enforcement sites. Specifically, a recent review of OWPE's Case Management System (CMS) showed that of the 157 sites listed as stateled enforcement, only 44 have a negotiation activity listing (Removal, RI/FS, RD/RA or other). Of the 44 sites, 21 were listed as having initiated negotiations with PRPs to conduct the activity. Of the 21 sites, only 7 had information on the type of negotiation taking place (administrative order, judicial action, cost recovery, etc.).

In response to this problem, the Assistant Administrator, Office of Solid Waste and Emergency Response issued a memorandum on March 14, 1986, reiterating the principles of information exchange set forth in the U.S. EPA/ASTSWMO joint policy.⁸ The memorandum also encouraged U.S. EPA regional offices to enhance the quality of information available on stateled enforcement sites. As an initial step, OWPE conducted a survey and categorized each site by the type of enforcement action taking place. The regional offices are now routinely updating this information on a quarterly basis. In addition to this new regional reporting requirement, the Agency is continuing to work with ASTSWMO to develop additional state reporting requirements and address the information needs of states at Federal-led enforcement sites.

EFFECTS OF CERCLA REAUTHORIZATION ON THE U.S. EPA/STATE RELATIONSHIP

Thus far, the discussion has focused on the increased role of states as they pursue enforcement actions at NPL sites. However, CERCLA reauthorization will provide new, expanded opportunities for state involvement in Federal enforcement actions as well.

As of this writing, specific language agreed upon by House and Senate conferees has not become final. In general, the following requirements will be added to the legislation.

- Specifically referencing "enforcement" under Section 104(d) as a fundable activity through contracts and cooperative agreements
- Applying state standards to on-site and off-site response actions carried out under Section 106 of CERCLA
- Developing regulations for state involvement in the CERCLA enforcement process

 Providing state concurrences for Section 106 enforcement actions and Federal facilities response actions

CERCLA reauthorization is consistent with and supports the U.S. EPA's current efforts to fund states during their enforcement actions at NPL sites. However, some revisions to the pending guidance documents will be required based on new or revised requirements outlined in other sections of the Act.

Specific requirements for applying state standards to on-site and off-site response actions under Section 106 will be required upon CERCLA reauthorization. For on-site actions, the need to attain applicable or relevant and appropriate requirements (ARARs) will apply to any promulgated state requirement or facility siting law that is more stringent than any Federal requirement and that has been identified to the U.S. EPA in a timely manner. These requirements will apply unless they result in a statewide ban on land disposal, except where certain factors outlined in CERCLA reauthorization are met. A remedial action that protects human health and the environment, but does not meet ARARs for on-site actions, can be selected if certain waivers also outlined in CERCLA reauthorization exist. For off-site actions, hazardous substances, pollutants or contaminants can be taken only to facilities operating in compliance with RCRA or other Federal laws where applicable.

CERCLA reauthorization also establishes a formal process for state involvement in NPL site cleanups. The U.S. EPA must promulgate regulations for substantial and meaningful involvement in the initiation, development and selection of remedial actions. With regard to CERCLA enforcement sites, this will include participating in negotiations with PRPs, reviewing and commenting on RI/FS, RD and RA and commenting on the selection of remedy.

State involvement requirements also will apply to enforcement actions taken under Section 106 of CERCLA and actions at Federal facilities. For Section 106 actions, CERCLA reauthorization provides opportunity for state concurrence and establishes a process for state intervention before entry of a consent decree and circumstances under which a remedial action would be required to comply with ARARs. For Federal facilities, opportunity for state concurrence also is provided as well as allowing states to bring action in court to determine whether the action should conform to state requirements.

CONCLUSION

In conclusion, the sum total of these efforts to carve states a larger role in taking their own enforcement actions and to provide a better avenue of involvement in Federal enforcement actions should lead to a more coordinated and successful CERCLA enforcement program. As the Agency continues to implement the U.S. EPA/ASTSWMO joint policy recommendations and begins to formulate specific policy and guidance on the new statutory requirements, the continued cooperation from associations such as ASTSWMO and the National Association of Attorneys General (NAAG) will be sought. So far, the cooperation of these groups has added to the quality and acceptability of Agency decisions on state participation and should continue to be valuable in the future.

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The Effect of the National Contingency Plan Revisions on Federal, State and Private Superfund Cleanup Actions

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ABSTRACT

On November 20, 1985, the U.S. EPA published a revised National Contingency Plan (NCP). (See, Fed. Reg. 59, 479 et seq.) The revised NCP has substantially altered the criteria for government and private party action under CERCLA and has far reaching effects on all parties involved in the CERCLA process. Short-term actions known as removals are easier to justify and will occur more frequently and the cleanup standards for longer term, remedial actions have become more stringent and complex. The revised NCP now provides community groups with formal intervention into the decision-making process and provides a framework for private parties to sue those responsible for hazardous waste releases. As a result of these changes, the cost of CERCLA actions is almost certain to increase as well as the volume of lawsuits initiated by private parties.

INTRODUCTION

The National Oil and Hazardous Substances Contingency Plan (NCP) outlines the operating procedures and response mechanisms for the government's actions under CERCLA, otherwise known as Superfund (42 U.S.C. §9601 *et seq.*). The existing NCP was published in the *Federal Register* on July 16, 1982 at 40 CFR Part 300 (47 *Fed. Reg.* 31180-31243).

After two and one-half years of implementation, the U.S. EPA has determined that substantial revision to the NCP could increase its ability to effectuate enforcement actions, foster private party settlements and streamline Fund-financed cleanups. In certain respects, the existing NCP restricted the authorities granted to the U.S. EPA under CERCLA. Because many program constraints which were the outgrowth of litigation challenging the NCP (*EDF V. U.S. EPA*, (No. 82-2234, D.C. Cir., February 1, 1984); *State of New Jersey v. U.S. EPA*, (No. 82-2238, D.C. Cir., February 1, 1984) (the EDF Consent Decree), proved unduly restriction, the U.S. EPA decided to revise the NCP.

Pursuant to the EDF Consent Decree, the U.S. EPA agreed to base cleanup levels on U.S. EPA-developed standards and criteria, whenever applicable, institute a formal community relations program and determine the need to comply with other federal, state and local laws.

The proposed NCP changes address many difficult issues facing the program and, individually, are very significant. However, when viewed as a whole and when their interrelationships are fully understood, they signal a revolutionary approach to the Superfund Program. This paper outlines the major NCP revisions and evaluates cross-cutting impacts of these changes.

THE REMOVAL PROGRAM

Removal actions may be taken at any facility, whether or not it is listed on the National Priorities List (NPL). Removal actions are statutorily limited to \$1 million or 6 months duration unless an emergency condition continues to exist. Historically, removal actions were considered emergency response measures to abate life-threatening conditions posed by hazardous substance releases. Typical removal situations were tank car derailments, fires at storage facilities or serious groundwater contamination.

The removal program was basically a continuation of the U.S. EPA's oil spill program established under the Clean Water Act. Consistent with its origin, the prior NCP substantially restricted the circumstances permitting a removal action. The removal criteria required a determination that "the initiation of immediate removal action will prevent or mitigate immediate and significant risk of harm to human life or health or to the environment...."

Under the proposed NCP, the ability to take removal actions will be greatly expanded by reducing the threshold that triggers such action. Removal actions now may be taken where "there is a threat to public health, welfare or the environment. . ." (See 40 CFR \$300.65(b)(1). The proposed NCP includes several factors indicating a threat. Most factors require a determination of whether there is an exposure to or release of a hazardous substance. This avoids the need to quantify the magnitude of the threat associated with the conditions. Essentially, a threat sufficient to trigger removal action exists whenever a release or threat of release of a hazardous substance may occur.

The proposed revisions also outline typical response actions for typical removal situations. For example, capping of contaminated soils or sludges is considered appropriate where needed to reduce migration of hazardous substances into the soil, groundwater or air. This section establishes a presumption that the U.S. EPA has taken action "consistent with the NCP," which is a requirement for cost recovery pursuant to CERCLA §107.

The U.S. EPA's primary reason for the proposed changes is to reduce its burden in cost recovery actions. Properly demonstrating that an immediate and significant risk existed required an expert witness presentation of detailed technical analyses. U.S. EPA personnel executing removal actions usually were not qualified for this evaluation. The new factors that trigger removal action involve determinations that can be made without such "health experts."

This NCP revision raises the issue of whether the U.S. EPA may take a removal action whenever any release of a hazardous substance occurs, or whether a minimum threshold threat to the public or the environment must be crossed before the statute authorizes the U.S. EPA to respond (as is the case with most other environmental statutes). The U.S. EPA's proposal has serious implications because under CERCLA and the NCP anyone may undertake a removal action if the criteria are met.

The U.S. EPA position is: If a release occurs, assume that a

threat exists and removal action is authorized. Arguably, the U.S. EPA's position is inconsistent with several provisions of the Act: the requirement to investigate the extent of threat first (CERCLA §104[b]); allowance for federally permitted releases (CERCLA §101[10]); notification of only releases exceeding reportable quantities (CERCLA §103); definition of removal which includes actions necessary to protect public health (CERCLA §101[23]); and the requirement that standards (i.e., thresholds) be established for removal actions (CERCLA §105).

Although the U.S. EPA is likely to exercise its removal authority only in response to serious threats, consistent with its current approach, private parties need not exhibit such discretion. The NCP proposal allows anyone to initiate removal actions at *de minimis* releases which unfortunately could divert responsible party resources from more substantial threats.

COMMUNITY RELATIONS PROGRAM

The proposed NCP formally institutes a Community Relations (CR) program for removal actions that extend over 45 days, remedial actions and enforcement actions. The CR program is designed to provide the public with accurate information about site conditions and give citizens the opportunity to comment on the technical remedies proposed. Where applicable, formal CR plans must be developed and approved prior to the initiation of field activities. These plans will be implemented during the course of the action, typically through workshops, press releases and public hearings.

Responsible parties will be allowed to develop and implement CR plans with U.S. EPA oversight. This condition provides the responsible parties the opportunity to improve their community image and present all the information necessary to assure the public that adequate protection will be provided.

The CR program is the U.S. EPA's way of achieving "functional equivalency" with the federal NEPA process. In other U.S. EPA programs, such as Construction Grants under the Clean Water Act or the RCRA permitting, public participation has had a strong influence over pollution control decisions. Because the CR program provides the public with a similar mechanism to influence response decisions, it may result in greater consideration of community concerns over acceptable remedial alternatives and levels of cleanup.

REMEDIAL ACTION

Remedial actions are long-term, permanent remedies to minimize or prevent hazardous substance releases. Unlike removal actions, they are not limited in cost and may be taken only after extensive analysis of site conditions. Fund-financed remedial actions may be taken only at NPL sites.

As in the removal program, the U.S. EPA has proposed several new factors that must be considered in developing remedial action alternatives. The most significant revisions to the remedial program address the "how clean is clean" issue and provide detailed guidance on developing remedial action alternatives. The proposed changes operate to restrict the U.S. EPA's discretion in choosing the cost-effective alternative and provide a bias toward more permanent remedies.

Of all the proposed changes to the remedial program, undoubtedly the most controversial is the U.S. EPA's attempt to define the level of cleanup required at a particular site—the "how clean is clean" issue. The proposed approach involves assessment of exposures, determination of applicable or relevant (AOR) standards and criteria and integration of the exposure analysis with the AOR standard to insure that adequate/consistent public health and environmental protection is achieved. If there are no AOR standards, a risk analysis of existing and projected exposure levels is required. Although the generic framework is logical, the proposed NCP provides little guidance over the existing NCP on the issue of "how clean is clean." A brief walk through the new maze will illuminate some of the problems.

An exposure assessment, which is the first step in the process, determines the degree and routes of exposure to the environment and local population. It also assesses residual exposures from remedial alternatives. However, one cannot evaluate the level of exposure or associated risks until the point of exposure is determined.

Whether one assumes that the exposed population is living just beyond the security fence of the waste site or one-half mile away at the closest house makes a tremendous difference in the lifetime exposure calculated. Drinking water contamination highlights this issue. In most instances, drinking water contamination is lower at the tap while portions of the aquifer may be much more contaminated. Should the U.S. EPA assume that in the future someone will drill a well into the contaminated area or only base evaluations on the existing situation? Under RCRA, the point of compliance is generally the boundary line of the facility. However, this may be a very unrealistic point to evaluate a lifetime exposure. One can probably expect the U.S. EPA and the responsible parties to calculate exposure levels at several points, and then argue over which is the "most reasonable" because the NCP is silent on the issue.

After the exposure is calculated, it must be compared to some public health or environmental standard to determine the necessary level of cleanup. However, one must first determine if there are any AOR standards. This is no small task. There are no Superfund standards, per se, only standards developed under other programs (air quality standards, water quality standards, etc.). However, each program has different guidelines on the level of protection and application of the standards. No standards have been developed incorporating the multiple chemical, multiple routes of exposure problem encountered at Superfund sites. Therefore, each AOR standard must be reevalulated individually to be useful for determining the appropriate remedial alternatives.

To provide further guidance on how to select AOR standards, the U.S. EPA has published a draft memorandum entitled "CERCLA Compliance With Other Environmental Statutes," that outlines the types of standards and criteria that normally may be AOR. The draft policy lists virtually every ambient and technology-based standard or criterion ever developed by the U.S. EPA. The U.S. EPA's policy merely restates the obvious and provides little additional guidance.

The U.S. EPA's broad interpretation of potential AOR standards and criteria goes far beyond the intention of the parties entering into the EDF Consent Decree which spawned this requirement. The intent of those parties was to use ambient standards such as air quality standards or water quality standards to determine cleanup levels. However, the U.S. EPA has taken this ambient standard requirement one step further by stating that technology-based standards such as RCRA standards are presumed AOR. The obvious implication is that all Superfund sites must meet RCRA standards to comply with the NCP. Mandating blanket compliance with RCRA is an incredible waste of resources, offers virtually no environmental benefit in many instances and contradicts the basic statutory framework established under CERCLA.

To analyze whether or not RCRA technology-based standards should be applied, one must contrast the essence of CERCLA and the reasons for the development of the RCRA standards. CERCLA is a health-based statute directed at tailoring site specific remedies to address individual problems arising from past disposal of hazardous substances. CERCLA contains no discernible mandate to develop a uniform technology-based approach that may or may not be relevant to a particular site. On the other hand, RCRA is primarily a prospective regulatory program to
control the hazardous waste disposal industry. For this reason, uniform standards were desirable and required by law.

The basic statutory inconsistency with imposing RCRA standards at Superfund sites is that RCRA standards are required regardless of their environmental or public health need or costeffectiveness in providing public health protection. Because RCRA standards are non-site specific, their implementation at all Superfund sites typically may result in non-cost-effective expenditures which would preclude fund-financed cleanup under the Act. (See CERCLA §104[C][4]).

Because of the limited number of ambient standards, few standards, other than RCRA standards, are likely to be AOR. Where no AOR standards exist, a risk assessment is necessary to determine the appropriate remedy. Therefore, risk assessments are likely to become the norm rather than the exception.

Under present U.S. EPA risk assessment policies, conservative assumptions often are used to compensate for insufficient data. High safety factors result from compounding these conservative assumptions dictating the need for, at times, unnecessarily stringent controls.

Realizing this, responsible parties should obtain as much data as possible to accurately calculate the risks. Review of the U.S. EPA risk assessment should reveal the critical data gaps that most influence the treatment decision. It is prudent for parties to invest funds to accurately assess risks where a \$5 to \$50 million difference in treatment requirements is at stake. Where "Star Wars" was the novelty of the 70s, "Data Wars" will be the buzzword of the 80s.

Under the proposed NCP, there is one critical point that should be noted in the application of AOR standards. An exception to this requirement is permitted for enforcement actions where there is a strong public interest to expedite the cleanup and litigation probably would not result in the desired remedy. One finds it unusual that the U.S. EPA is providing an incentive for responsible parties to litigate the U.S. EPA's overly enthusiastic application of questionable standards. The more rigorously the U.S. EPA attempts to apply RCRA standards at Superfund sites, the more likely the U.S. EPA is to invoke the litigation exception to avoid the application of those standards because responsible parties refuse to execute unreasonable cleanup orders. Excessive costs will drive responsible parties to rely on the court's common sense in reviewing application of RCRA standards. Hopefully, the U.S. EPA will take a more prudent and technically defensible position in AOR determinations to avoid this outcome.

Several other proposed changes are noteworthy. In reviewing off-site disposal alternatives, the U.S. EPA now is required to investigate potential migration at the eventual RCRA disposal facility. This helps to ensure that a new problem is not created in remedying the existing one. Review of prior U.S. EPA response actions suggests that, at times, wastes have been sent to disposal facilities that are not likely to meet all RCRA operating requirements and therefore, may close in the future. These future Superfund sites may have the U.S. EPA as a responsible party for cleaning up the residual hazardous waste.

Although intended as an additional check on RCRA facilities, this requirement may have several unintended side effects. For instance, community pressure to relocate waste could be offset by this requirement. Investigation of potential migration also may force the U.S. EPA to follow the Act's preference for on-site management more closely. (See CERCLA §102[24]). To the extent that the U.S. EPA favors on-site containment, remedial response costs should decrease substantially.

The ability of the responsible party to implement and maintain a remedy until the threat is permanently abated will be considered in selecting the appropriate enforcement remedy. If circumstances warrant, the U.S. EPA will require a more capital intensive, permanent solution rather than a less expensive alternative which depends upon future maintenance by the responsible party for its effectiveness. This helps the U.S. EPA to avoid the possibility of future bankruptcy or neglect by the responsible party that might require the U.S. EPA to subsequently maintain the project. One can expect responsible parties to vehemently oppose U.S. EPA selection of capital intensive alternatives where less expensive alternatives with long-term maintenance can be properly managed. In such situations, the U.S. EPA may require a performance bond from the responsible parties to guarantee proper maintenance.

PRIVATE PARTY ACTIONS

CERCLA §107 allows any person (including responsible parties) to respond to a hazardous substance release and bring a cost recovery action against those responsible for the release. Response costs are recoverable if incurred "consistent with the National Contingency Plan." This provides a mechanism for persons to address releases that the U.S. EPA or states may not address due to other priorities and for responsible parties to share the costs of compliance.

Over the past three years, courts have struggled with numerous issues raised in private party actions under CERCLA. The courts currently are split on several issues: (1) whether sites must be on the NPL as a prerequisite to cost recovery; (2) whether prior government approval of the cleanup plan is necessary; and (3) whether responsible parties may initiate actions for contribution under CERCLA §107.

To increase the ability of other parties (e.g., private parties or responsible parties) to execute cleanup actions and obtain cost recovery or apportionment from responsible parties, a new NCP section entitled "Other Party Responses" addresses the above issues. The section states:

> "any person may undertake a response action to reduce or eliminate a release or threat of release. Section 107 authorizes persons to recover response cost consistent with this Plan from responsible parties."

The section specifies the NCP provisions one must follow to be "consistent with the National Contingency Plan."

The U.S. EPA's ostensible intent is to enhance settlement possibilities by establishing a framework for contribution actions within the NCP. By clarifying the U.S. EPA's interpretation of the right of contribution under CERCLA, uncertainty over the ability of responsible parties to obtain contribution is reduced. If contribution is possible, responsible parties are more likely to settle. The success of this incentive will depend upon the cost of the subsequent contribution litigation and the ability of responsible parties to obtain the information the U.S. EPA possesses concerning liability of other parties at the site. Promoting private party actions should increase the overall number of response actions because responsible parties can more readily be sued by private parties, possibly community groups, who wish to clean up sites that are not U.S. EPA priorities.

The proposed NCP states that prior governmental approval of private party response measures is not required unless the response involves an administrative order or fund preauthorization (i.e., a request for the Fund to pay for cleanup costs).

Even with the proposed changes, a private party's ability to obtain cost recovery for remedial actions will be difficult due to the technical complexity of such actions. However, one can expect a torrent of removal action suits because of the reduced burden of proof necessary to justify removal action. As previously discussed, removal actions are justified if a "threat to public health, welfare or the environment" exists which is demonstrated by the existence of a physical condition on the site. Such conditions might be rusting drums, contaminated soils on the surface or the ability to walk on the site and receive an exposure. A film clip of the site conditions in addition to some minimal sampling probably would suffice to support a cost recovery action.

Because the U.S. EPA has listed a series of removal actions considered appropriate to address specific threats, it is easy for a party to prove consistency with the NCP where a condition existed and the specific remedy listed by the U.S. EPA was executed. The only solace that a responsible party may have is that his liability under the removal section generally will be limited to a million dollars.

There is one substantial stumbling block to the initiation of private party action. Prior to initiating action, the private party must obtain any applicable federal, state and local permits. The permit requirement again raises the RCRA issues previously discussed. As long as the action does not include management of the hazardous waste, RCRA permit requirements should not be triggered. Such actions as placing security fencing around the site, installation of dikes and berms to prevent runoff, or the placement of a cap over the site, consistent with the U.S. EPA's interpretations, are not management of a hazardous waste. Where the private party seeks to move the waste off-site or drain a lagoon that contains hazardous waste, RCRA requirements must be met. The issue that the private party must face is whether to incur the potential liability that results from waste management or settle for on-site containment.

Concerning releases from liability, the section states that "implementation of response measures by responsible parties, certified organizations or other persons does not relieve those parties from liability." The purpose of this statement is two-fold. First, where a responsible party has executed a response action pursuant to an enforcement order, the U.S. EPA maintains that a blanket release from subsequent liability will not be given. Second, the U.S. EPA was concerned that parties may take a partial cleanup action that does not meet the U.S. EPA's expectations. Responsible parties should be aware that the U.S. EPA may subsequently require additional response measures which the responsible parties would be expected to fund.

Although the possibility of subsequent U.S. EPA action is always present, the likelihood of such an occurrence is slim, especially for non-NPL sites. Given the tremendous workload that the U.S. EPA has in regulating and responding to releases at NPL sites and other high threat removal sites, the U.S. EPA is not likely to second guess private party cleanup actions where good faith efforts have been made to prevent further hazardous substance releases. Realizing this situation, it may be in the best interest of responsible parties to execute their own cleanup actions, preferably with some U.S. EPA or state oversight, because the likelihood of future governmental action is minimal.

The final point that deserves attention is the U.S. EPA's recognition of private party fund preauthorization. Fund preauthorization provides assurances that if a response action is taken consistent with a plan of action approved by the U.S. EPA, Superfund monies will be available to reimburse that party for response costs. This is particularly important in those instances where a responsible party is only liable for a percentage of the cleanup cost yet still wishes to conduct the response action to keep costs down. In such cases, the U.S. EPA may contribute the balance to execute a full response action.

Fund pre-authorization will be granted only for response actions at NPL sites, removal action and CERCLA §104(b) activities (i.e., site investigations). The critical point to note is that almost any release can meet the new criteria established for removals. Therefore, almost any release could be eligible for Fund preauthorization and a guarantee that Superfund monies will be available to offset costs incurred. To the degree that the U.S. EPA has increased the exposure of responsible parties to pay for removal costs, they also have exposed the Superfund.

It will be interesting to see how the U.S. EPA treats preauthorization requests for removal actions. In many instances, even where viable responsible parties may exist, one would expect parties executing removal actions to prefer to obtain preauthorization rather than litigate a cost recovery action. Supposedly, the U.S. EPA will only grant preauthorization for releases considered a priority to avoid diversion of Superfund monies to lesser threats. In practice, this is likely to turn into a "first come first serve" priority system because of the substantial efforts that would be required to investigate every request for preauthorization and to prioritize those requests.

CONCLUSIONS

The proposed changes in the NCP would greatly expand the authority and powers of the U.S. EPA and other parties to execute response actions and obtain cost recovery from those responsible for the releases. One can expect private party actions and suits against responsible parties for contribution to increase substantially as a result of the proposed changes and the success rate of those actions to increase markedly.

The net effect of the proposed changes to the removal program is that more removal actions can be taken and costs can be recovered more readily. Where typical removal actions are executed by the U.S. EPA or a private party to address a typical condition, courts will be compelled to find them consistent with the NCP and award cost recovery pursuant to CERCLA §107. The new removal section greatly increases the potential liability of responsible parties.

The development of more accurate and detailed public health and environmental impacts information will now play a critical role in choosing the appropriate extent of response. Although this may slow the decision-making process, the net impact on producing quality alternatives should be a positive one. Unfortunately, U.S. EPA's attempt to address the "how clean is clean" issue has failed to resolve the most pressing issues. In addition, inflexible application of RCRA standards that may have little or no technical relevance for implementing a cost-effective remedy to protect public health, welfare or the environment would significantly hamper cleanup progress. One can only hope that a reasonable approach will be taken in this regard.

Communities affected by hazardous waste sites and interested parties concerned about the level of control that the U.S. EPA has proposed for a Superfund site have received several new tools to control and accelerate the process. The Community Relations Program offers the opportunity for direct involvement in the selection of response alternatives, and the preauthorization section helps communities take direct action.

Expansion of program flexibility increases the possibility that the U.S. EPA and other parties may take arbitrary actions. To that extent, the program and responsible parties may suffer unless increased supervision is instituted. If the necessary supervision is not provided by the U.S. EPA, undoubtedly it will fall to the courts. If this occurs, program flexibility achieved through rulemaking will be narrowed to prevent arbitrary results. Only time will tell.

The Community Relations Benefits of Resolving Private Property Legal Issues

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ABSTRACT

The Bunker Hill Superfund site in northern Idaho is one of the largest and most complex sites in the country. Much of the contaminated property within the site is private residential or commercial property not owned by the Potential Responsible Party.

Cleanup of private property presents unique legal and community relations problems. Sharing authority with local interests can be used successfully to prevent disgruntled local interests from using politics or lawsuits to seize control from the project managers. Fast-track, an interim removal cleanup program at the site, is an example of how authority can be effectively shared and legal and community relations problems can be solved in a unique and successful way.

A local private attorney was retained to address the concerns of the property owners whose property was to be cleaned up in Fast-track. This approach enhanced community relations, avoided potential legal difficulties and helped complete the project on schedule.

INTRODUCTION

Many CERCLA actions involve cleanups in small company towns. Special community relations and legal problems develop when these cleanups are of private residential or commercial property not owned by the potentially responsible party (PRP). The community often sides with the PRP, being more concerned with jobs than with health. Entering such a community to clean it up can be as dangerous for the Superfund project team as entering the cage of an ailing grizzly bear to doctor it. The bear is probably more likely to maul the doctor than to accept the medication.

The Bunker Hill site project team recognized the need for an effective community relations program. Project authority was shared with local interest, and a local private attorney was retained to deal with legal issues and concerns raised by private property owners in the cleanup of their property. This paper analyzes the success of that approach.

In the paper, the authors first discuss the background of the Bunker Hill site. Next, the authors discuss the strategy developed by the project team (project managers and contractors) to address the site. The paper focuses on one aspect of that strategy—the community relations program which retained a local private attorney to address private property legal concerns raised by the owners of the property to be cleaned up.

BACKGROUND

The Bunker Hill site represents one of the largest and most complex projects in the country. It is an NPL site. It was also the focus of a Natural Resources damage suit instituted by the State of Idaho. Significant public health damage has been associated with past smelter operations at the Bunker Hill site. This area was long the center of one of the world's largest lead, zinc and silver mining and smelting industries. The NPL site contains four incorporated cities and about 5,000 people. The smelter complex encompasses nearly 500 acres including a primary lead smelter, an electrolytic zinc plant, an ammonium phosphate fertilizer plant, a mine and mill operation, nearly 200 acres of impounded tailings and numerous ancillary facilities. The lead/zinc smelter closed in 1981.

Several important environmental features are found outside the smelter complex but within the Bunker Hill NPL site boundaries. A large area of the river flood plain historically served as an impoundment area for mine waste discharges. Significant reworking of these tailings by both man and river has left deep beds of unconfined contaminants. Seepage from two large confined tailings impoundments has severely contaminated the groundwater. Soils throughout the site have been badly abused. Forest fires and indiscriminate timber harvesting early in this century denuded most of the hillsides in the area. Sulfur-oxides emissions in the following decades pre-empted regrowth. Subsequent erosion has resulted in high soil acidity and the loss of topsoil, texture and water holding capacity. Several thousand acres are almost barren as a result. Local soils are toxic and a risk to public health as a result of waste discharges, periodic floodings and years of smelter operations depositing high concentrations of heavy metals. In the majority of residential soils in three of the four cities within the NPL site, lead contamination levels exceed the CDC warning level of 500-1000 ppm lead. Cadmium, arsenic, mercury and other metals routinely are found above action levels suggested at other NPL sites.

The Bunker Hill area came to national attention in the mid-1970s when an epidemic of childhood lead poisoning was discovered following several months of smelter operations with severely damaged pollution control equipment. All of the children living within 1 mile of the smelting complex and the majority of those children living within the NPL site boundaries had excess blood lead absorption according to Center for Disease Control (CDC) criteria. More than 40 children had clinical lead poisoning and were treated as medical emergencies.

The state promulgated pollution control criteria, and a lead health program was established. These steps substantially reduced smelter emissions, and a corresponding decline in children's blood lead levels was noted. The smelter closure in 1981 resulted in an immediate decrease in air lead concentrations to near background levels. Blood lead levels, however, remained above CDC criteria. Two years after the smelter closed, 25% of the children living within 1 mile of the complex continued to exhibit high blood lead levels. The major suspected sources of this lead contamination were identified as contaminated residential soils and fugitive dusts emanating from roadsides and barren soils. Among the chief reasons for the U.S. EPA and state decision to proceed with RI/FS activities at the Bunker Hill site were the demonstrated health risks associated with the excess absorption in children and the severe contamination levels noted in local soils.

PROJECT STRATEGY

It is always difficult for a bureaucracy to decide who has a legitimate interest in project decision-making. Yet this project design is often one of the most crucial decisions in a project. Who is affected by a particular CERCLA project is, to a great extent, site-specific. The affected group depends on the magnitude of the release; the media involved; the degree of off-site penetration; the characteristics of the community, properties and resources affected; and the role of the PRPs in the local economy.

Local control allows those most affected to have the greatest say. But locals are often the most ill-informed, most prejudiced and most vulnerable to economic and social pressures from politically powerful PRPs. Including such groups in the decisionmaking process involves walking a fine line between facilitating a meaningful local program and losing control of the project. Unfortunately, there is no magic formula for resolving this dilemma.

One of the most effective methods of maintaining control of the project is a continuing education process. The lead agencies must educate and re-educate state and local interest groups. In turn, those agencies must allow themselves to be educated to the needs of local advocates. Each must respect the other's concerns as being equally relevant and important to the resolution of project issues.

Sharing the decision-making power with local individuals can be most difficult for traditional program managers, but if properly handled, it can help keep project managers from losing control of their projects to the courts or the political arena.

Both the U.S. EPA and the state recognized that the Bunker Hill site was among the nation's most complex with respect to size, number of persons, types of properties affected and degree of off-site contamination.

An innovative and well thought-out project strategy was required. Negotiations between the state and the U.S. EPA at the Bunker Hill site began with the state in an advocacy role for local interests. Understanding the ultimate project strategy requires some knowledge of local and state attitudes toward the problem. The state and county health officials had administered a lead health program for over 10 years. The area was suffering desperate social and economic problems associated with the loss of more than 3,000 jobs when the smelter closed. Although the degree of blood lead absorption exhibited by children in 1983 was among the highest in the country, these levels were the lowest they had been in over a decade. Community attention was focused more toward problems associated with the 40% unemployment rate than with decreasing blood lead levels. However, it was clear that the years of smelting and mining operations had left a legacy of residual contamination that represented a continuing threat to public health. This was bound to hinder future economic redevelopment.

State and community leaders recognized that a cleanup was essential to both public health and new economic development. However, there was a lingering resentment of the federal government. Environmental programs were blamed for the smelter closure and the resulting unemployment. The prognosis for a local or state endorsement of a federal environmental project in the area was grim. Negotiations between the state and the U.S. EPA resulted in a strategy that provided for joint administration of the project in a manner that could both meet program needs and provide for a maximum level of local involvement. The strategy called for state and local control in certain areas of the project. Four principal areas of investigation and remedial action were reserved for the state. Those were: (1) public health protection, (2) community relations, (3) socioeconomic impact evaluations and (4) remedial activities associated with soils contamination on public and private citizens' properties.

Total removal of the several thousand acres of contaminated community soils was not feasible. It was likely that the ultimate remedy would involve some combination of removal and limited institutional controls restricting access to or uses of certain properties. Developing such land use restrictions would require the cooperation of local governments, because, in Idaho, land use restrictions are the province of local government. Before local officials could be expected to adopt necessary land use ordinances, they would need to understand the legal, social and economic consequences. They also would need the support of their citizens.

The U.S. EPA and the state both realized that the development of such institutional programs in a hostile community would be a nearly impossible undertaking. An innovative three-pronged approach was chosen. The plan was to: (1) establish an aggressive public health intervention program, (2) create a local task force to monitor project efforts and (3) clean up the areas of potential highest exposure quickly (Fast-track).

Since the entire project would take several years to complete, the public health intervention program was necessary to meet the on-going blood lead absorption problem among area preschoolers. The first state action undertaken was an aggressive intervention program administered at the county level. Every home in the area was visited at least once a year by a nursing team. Children's lead absorption levels were monitored. If excess levels were found, children were addressed individually from both nursing and home environment perspectives. In 2 years, this program has successfully reduced excess absorption in the area to less than 2%.

Creation of a task force of local citizens was the second prong of the plan. This group was appointed by the local county commissioners. The task force monitored project efforts, participated in project decisions and acted as community advocates. Two-day meetings were held at the site each month. Complete project summaries were presented to the task force in an evening public forum. The forum included representatives from several area citizen, business and service groups. The task force was involved in both the selection of the sites to be cleaned up in Fasttrack and the selection of the appropriate remedial action for each site. The project managers and contractors provided the technical information. The task force provided the practical information of what cleanup approach would be most compatible with community use. The result was a constructive sharing of information. Appropriate cleanup solutions (remedial actions) were chosen which had broad based community support.

The third prong of the plan was to clean up some areas very quickly. Several public access areas such as parks, playgrounds and road shoulders were severely contaminated. They offered undue exposure to children. The interim removal program was used to clean up these properties quickly under a plan called Fasttrack.

Fast-track afforded the project the opportunity to actively involve the task force and local government officials in the decisionmaking process. Many of the lessons learned in Fast-track will be of great value in the ultimate clean-up at the Bunker Hill site. These lessons also may be of value in other Superfund projects where the property to be cleaned up does not belong to the PRP.

The remainder of this paper focuses on Fast-track's handling of legal property issues and community relations as they pertain to those legal issues.

FAST-TRACK

There are many aspects of Fast-track which could be discussed. However, the focus of this paper is on how the legal issues were handled as part of the community relations program.

As the construction date for Fast-track approached, the property owners (mostly local governmental entities) began to pose numerous questions about the proposed cleanup. Many of the questions were of a legal nature and concerned the property to be cleaned up. The projects managers and contractors viewed the legal questions as legitimate concerns which, if left unanswered, could cause community relations problems and jeopardize the project. It was obvious that the property owners could not afford to hire legal counsel to address the matters. The situation was complicated by the fact that two of the property owners were represented by the same legal firm which represented the PRP.

The solution adopted was to involve a local attorney through the state contractor. This attorney met with property owners and listened to their concerns and questions. These concerns dealt with knowing exactly what property was to be cleaned up, how the contaminated soil was to be disposed of, and a score of liability issues such as liability for refusing to allow the cleanup, liability for an inadequate cleanup, liability for maintenance of a partial cleanup and liability for participation as a subcontractor in the cleanup. There were also questions concerning compensation of the property owner by the U.S. EPA for any inconvenience and damages suffered by the property owner during the cleanup.

After meeting with the property owners, the attorney met with the project team to see what could be worked out. A report was prepared which listed the various concerns of the property owners and provided an analysis and recommendations to meet the expressed concerns.

Several unexpected bonuses resulted from this "before-thefact" legal involvement concerning actual property ownership. To make sure exactly who owned what property, the attorney recommended obtaining legal descriptions and title searches for all parcels. The proposed disposal site and some of the property to be cleaned up were owned by different parties than originally thought. This problem was determined early enough to find a new disposal site and to obtain consents from the proper parties. Rectifying this situation before cleanup prevented massive legal complications which could have arisen later.

In the liability area, the public entities were informed that there were some restrictions and potential liability if they acted as subcontractors, but they could do it under state law. They also were informed that they might have to pay Davis Bacon wages (despite the wording in 42 USC 9604(g)). However, the U.S. EPA later ruled that prevailing wages did not have to be paid. Property owners were advised of their potential liability for managing toxics left in place by the cleanup and who was liable for what if additional cleanup was necessary on the same property. Property owners also were informed of the U.S. EPA's options if the property owners refused to consent to the cleanup.

One issue which should be discussed in some detail dealt with compensation of the property owned by the U.S. EPA. The property owners felt they were entitled to some compensation for allowing the U.S. EPA and the state to come on to their property and alter it in some way.

Cleaning up non-PRP property poses unique legal issues. The United States Constitution allows the government to use or take private property, but the property owner is entitled to compensation for that taking. This process can be done by consent or through a condemnation proceeding. Government road building on private property would be an example of taking private property. There are other situations, however, where government can effect the use of private property without compensation. Zoning would be an example. Environmental regulation of property owners who are using their property in a way that is hazardous to the general public would be another example.

The property owner whose property has been dangerously contaminated by the act of another falls somewhere in between the road building and environmental regulation examples. His property in its present condition is a threat to the general public, but neither the property owner nor his predecessors in interest are in any way responsible for that threat. If the government determines that the property must be cleaned up to protect the public good, is this a taking requiring condemnation and compensation as in the road analogy, or is it more similar to zoning or environmental regulation where no compensation is required?

In this case, the property owners were not being greedy in asking about compensation. Instead, they were looking for a way to satisfy the 10% state match of the larger Superfund cleanup to come later. Idaho's Legislature had not established a method of raising the 10% state matching monies for Superfund. Given the state of Idaho's depressed economy and the legislative influence of some potential PRPs, local officials (the property owners) feared that the state might not be able to come up with the 10% match. The property owners wondered if they could assign their right to compensate from the U.S. EPA to the state who could in turn pledge it to the U.S. EPA as part of the state's 10% match. When cost recovery eventually was accomplished, the funds would revert to the property owners from the PRP.

Research disclosed no specific prohibition of this innovative approach. The U.S. EPA was intrigued but was reluctant to make any commitments within the tight timeframe of Fast-track. The result was to include a provision in the consent forms which reserved the issue of compensation for Fast-track until the larger cleanup was to take place. This is an excellent example of how a potentially thorny private property issue can be sidestepped for the time being and may eventually be turned to the benefit of the project.

This early legal involvement also provided the property owners with an analysis of the effect a parallel State Natural Resources Superfund suit would have on Fast-track. The inter-relationship of these two Superfund programs is a complex and fascinating issue, but it is beyond the scope of this paper. It is recommended that if faced with such overlapping suits, one proceed very carefully.

Involving a local, private attorney in Fast-track was very successful for a number of reasons. It was a clear statement to the community that the project team was willing to go to considerable lengths to address community concerns. All of the property owners signed written consents to have their property cleaned up under the plans outlined by the project team. Minor legal problems were identified and addressed so that the project could proceed on schedule. Legal questions which could have grown into lawsuits were dealt with to allow the project to proceed. Most important, involvement of the local attorney to negotiate with the U.S. EPA before minor issues became major problems helped the project managers keep control of the project.

CONCLUSION

Some large Superfund projects involve cleaning up private residential or commercial property not owned by the PRP. This cleanup of private property presents unique community relations and legal issues which are often entwined. Sharing authority with local interests and an effective community relations program which includes addressing local legal concerns can reduce the possibility that disgruntled local interests will use politics or the courts to take control of the project out of the hands of the project officers.

At the Bunker Hill site, local private counsel was hired to address legal concerns of the property owners as part of the project's community relations program. This approach, unique to Superfund, was very successful. It built trust in the community by showing that the project team was serious about addressing community concerns. It identified potential legal trouble spots which could be resolved before they became lawsuits or stumbling blocks which delayed the project. It provided the benefit of a different legal perspective—just as a private construction company can do some road jobs better than a government crew, so too, are there places where a private attorney is preferable to a government attorney. The project team deserves considerable credit for innovatively involving local legal counsel at an early stage of the proceeding. By integrating this legal component into their community relations program, the project team was able to complete this project on time without having to contend with lawsuits or political pressure.

Private property legal issues always will be matters of great community concern in any Superfund project cleaning up residential or commercial property not owned by the PRP. If the Superfund projects' managers recognize the importance of sharing authority with local interests and addressing private property legal concerns through a good community relations effort, managers can enhance community support for the clean-up, reduce present and future legal problems and stand a much better chance of completing their projects on schedule without political or judicial interference.

Remedial Planning Contracts

Nancy M. Willis U.S. Environmental Protection Agency Remedial Action Contracts Branch Washington, D.C.

NEED

The U.S. EPA has identified 888 uncontrolled hazardous waste sites as being a high priority for cleanup. These sites are either on or proposed for the National Priorities List. Under the Superfund law, these sites may be cleaned up by the states with Superfund dollars under a cooperative agreement with U.S. EPA, or U.S. EPA may take responsibility for the remedial response. The agency has contracted with engineering firms to conduct the studies leading to selection of a remedy for these sites when the U.S. EPA has the lead for the remedy.

STRATEGY

The current remedial planning contracts were designed to:

- Provide engineering services to conduct remedial investigations, feasibility studies and other technical studies for federalled remedial sites
- Provide this support in a manner flexible enough to accommodate fluctuating workloads

EXISTING CONTRACTS

U.S. EPA has three large remedial planning contracts:

• REM II	
Prime	- Camp, Dresser and McKee
Period of	
Performance	-June 1984 - June 1988
Area of	
Responsibility	- National
• REM III	
Prime	- EBASCO
Period of	
Performance	November 1985 - October 1990
Area of	
Responsibility	Region I - Revion IV
• REM IV	
Prime	- CH2M Hill
Period of	
Performance	-November 1985 - October 1990
Area of	
Responsibility	- Region V - Region X

STATEMENT OF WORK

The scope of these contracts is written broadly to include all of

the services needed to support the remedial program. Major areas covered are:

- Remedial Investigations
- Feasibility Studies
- Design of Remedial Actions
- Implementation of Small Remedial Actions
- Oversight and Support of Remedial Response Actions Conducted by Other Parties
- Enforcement Support
- Community Relations
- Quality Assurance
- Data Management
- Laboratory Support
- Technical Support
- RCRA Support

STRUCTURE OF THE CONTRACTS

All of the remedial planning contracts have three major components:

- Program management hours
- Level of effort hours
- Subcontract pool

PROCUREMENT

These contracts were procured using a Brooks Act procurement; the firms competing were evaluated and the most technically qualified firm selected. The factors considered in selection included:

- Demonstrated corporate and individual experience in performing remedial planning activities
- · Capacity to perform in a timely way
- Experience in large, multi-discipline, multi-task order contracts
- Adequacy of the management plan for supporting the contract
- · Quality of the response to management and technical problems

The selection processes resulted in cost reimbursement plus award fee contracts.

FUTURE

The Field Investigation Team Contracts— Scope and Functions

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INTRODUCTION

The purpose of the Field Investigation Team (FIT) contract(s) is to provide technical support to the U.S. EPA to perform preremedial investigative activities at hazardous waste disposal sites. The U.S. EPA has relied on FIT contractor resources since 1980. The existing FIT contracts are a part of the Zone (1 & II) REM/ FIT contracts which were awarded on Oct. 1, 1982, and will expire on Sept. 30, 1986.

The FIT contracts constitute the primary capability of the Federal government for assessing, inspecting and ranking hazardous waste sites. Specifically, the FIT contracts:

- Establish priorities for remedial action through Hazard Ranking System (HRS) scoring and National Priorities List (NPL) support
- Perform preliminary assessments (PAs) and site inspections (SIs) to determine the nature of the problem at sites on the CERCLA inventory
- Support enforcement case development
- Support special studies (e.g., dioxin, RI support)
- Support state PA/SI program (i.e., training) and
- Give general technical assistance

DESCRIPTION OF WORK FUNCTIONS

Preliminary Assessment

A PA is the first step taken after the U.S. EPA or a state discovers a site. It involves reviewing existing information and assessing current site conditions to determine if a potential threat to the public or the environment exists. A PA may, but often does not, involve a site visit. Sampling rarely is performed. The need for a site inspection (SI) is based on the results of the PA.

Site Inspection

The purpose of a site inspection (SI) is to gather additional data sufficient to rank the site using the HRS and to aid in making judgments on what further actions are required at the site. Historically, an SI involves a visual inspection of a site and usually includes limited sample collection.

A current initiative is underway to expand the scope of an SI to provide better support to the development of the Remedial Investigation (RI) work plan and scope. This expanded SI (ESI) would also provide better support for the HRS, NPL and related program needs.

Enforcement Support

Enforcement support embraces a wide variety of technical activities whose purpose is to support enforcement case development and litigation, perform oversight or monitoring of responsible party actions and generally augment the TES contract resources by performing technical field activities. While RIs are within the scope of work for the next FIT contract(s), it is not anticipated that this will be a routine function.

Quality Assurance Support

Quality Assurance (QA) support is related primarily to the review of Contract Laboratory Program (CLP) data for samples taken by FIT during field activities. FIT currently provides backup for U.S. EPA Regional staff responsible for this activity because of the heavy workload. Certain QA functions also are associated with routine technical activities.

Hazard Ranking Scoring

The application of the Hazard Ranking Scoring (HRS) is used to determine a site's potential for inclusion on the NPL. This determination includes background documentation and support through QA/QC.

Special Studies

Special studies include unusual investigations often involving "unconventional" sites, such as areas affected by Dioxin or pesticide contamination, underground storage tanks, potential RCRA Subtitle C facilities or small quantity generating facilities. Involvement in these areas has been on a case by case basis, following upper management decisions. Many of these areas may be excluded in the near future, depending upon specific provisions of CERCLA reauthorization legislation and EPA policy. Special studies also include efforts such as: discovery projects, NPL deletions and other various types of site investigations.

Training

Training includes basic and refresher training of FIT personnel in health and safety, site inspections, sample handling, HRS, etc., as well as training support for U.S. EPA, state and other contractor personnel.

Equipment Calibration and Maintenance

The area includes the necessary maintenance of the field equipment and the calibration and standardization of the hand-held analytical instruments used in gas chromatographic screening of samples.

General Technical Assistance

General technical assistance includes literature searches, reviews of other party reports and data, support in development of national guidance or standard operating policies, preparation of information for public information and similar support functions which do not fall into investigative activities listed earlier.

Program Management

Program management involves the administrative and managerial functions necessary to operate the contract. This includes FIT Regional managers and the Zone Program Management Office (ZPMO). The ZPMO staff has managers for the following operations: QA, subcontracts, technical operations, management information systems and reports and the overall Program Manager.

Subcontract Support

A pool of money is specifically set aside and tracked to finance subcontractor services. These support services are not provided through either the dedicated ZPMO or Regional FIT Office staffs. Services include: well drilling, geophysical investigation support, special consultants and analytical support.

SIZE AND COSTS OF EXISTING CONTRACTS

The current FIT portions of the REM/FIT Zone contracts

cost approximately \$35M for FY 85. The total estimated costs for the period of October 1982-Sept. 1986 are:

Level of Effort
171
194
365

SCOPE AND SIZE OF PROPOSED CONTRACTS

These will be 5-yr contracts starting at a 15% increase in level of effort or 422 personnel with an option available for a 50% increase in level of effort to 632 personnel.

Technical Enforcement Support Contracts

Nancy Deck

U.S. Environmental Protection Agency Office of Waste Programs Enforcement Washington, D.C.

WHAT IS TES

TES stands for Technical Enforcement Support. This covers enforcement support at hazardous waste sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA).

TES is the main contract mechanism for fulfilling and supporting the enforcement activities of the Office of Waste Programs Enforcement (OWPE) and EPA's Regions for their programs relating to the implementation of the CERCLA and RCRA laws. Four TES Contracts have been awarded to date.

WHAT TES DOES

The TES contractors provide technical support and the expertise necessary to accomplish OWPE's mission. Examples of activities tasked under these contracts are:

- Review of Technical Documents
- LOIS Inspections
- Facility Closure Plan Reviews
- RCRA Facility Assessment
- Comprehensive Groundwater Monitoring Evaluation
- Comprehensive Evaluation Inspections
- Enforcement Case Support
- Expert Witness Support
- Sampling Plans and Analysis
- Compliance Oversight/Audits
- Responsible Party Searches
- Endangerment/Health Assessments
- Records Compilation
- Hydrogeologic/Geologic Studies
- Title Search/Financial Assessments

THE TES CONTRACTS---RESOURCES AND PERSONNEL

TES I

The first TES Contract was awarded to GCA Corporation on June 9, 1983 and expired June 9, 1986. The TES I contract was a Level of Effort (LOE) contract with a \$14,649,129 capacity in its 3-year life. Their subcontractor team members were:

- Tech Law Inc.
- Metcalf & Eddy
- Clement and Associates

TES II

TES is a LOE contract. PRC (Planning Research Corporation) is the prime contractor. This contract was awarded Sept. 30, 1984 with a 2-year base capacity of 539,000 LOE hours and \$24,718,577. The option year was exercised, effective Oct. 1, 1986, with a capacity of 220,000 LOE hours and \$10,429,956. This contract will expire Sept. 30, 1987. TES II subcontractors are:

- Jacobs Engineering Group, Inc.
- GCA/Alliance Technology
- Versar, Inc.
- Booz-Allen & Hamilton
- ICAIR, Life Systems Inc.
- Intera/Geo Trans
- Putnam Hayes & Bartlett

TES II contract person-Nancy Deck, 382-3058.

TES III

TES III was awarded to Camp Dresser & McKee (CDM) on June 30, 1986. This is a cost-plus award fee contract. This contract has a capacity of 52.5 million and 1,050,000 LOE hours, over a 1-year base period and 2-year option period. This is a zone contract which mainly covers Regions 1-IV.

- The subcontractors are:
- Versar, Inc.
- Booz-Allen & Hamilton
- PRC
- Techlaw, Inc.
- Labat Anderson, Inc.
- Priede Sedgwick, Inc.
- Geoscience Consultants
- SRA Technologies
- Life Systems
- Hydraulic & Waste Resources Engineers
- AEPCO
- Sobotka & Company
- Geo Resources, Inc.
- Lee Wan & Associates
- Putnam Hayes & Bartlett

TES III contact is Linda Stewart, 382-2318.

TES IV

TES IV was recently awarded to Jacobs Engineering on Sept. 26, 1986. This contract is also a cost-plus award fee contract, and its capacity in LOE and dollar is the same as TES III. This contract will mainly support Regions V through X.

Jacobs subcontractors are:

- Metcalf & Eddy
- Tetra Tech
- ICA1R Life System
- Kellogg Corporation

- Putnam, Hayes, & Bartlett
- Geo/Resource Consultants
- Battelle Pacific Northwest Laboratories
- Development Planning and Research Associates

KEY PERSONNEL USED IN THE TES PROCESS

Some of the key personnel and their functions are:

- Contracting Officer—U.S. EPA headquarters employee with sole authority to execute contractual agreement, redirect contractor or modify terms of the contract.
- Project Officer—U.S. EPA headquarters employee in the Office of Waste Programs Enforcement (OWPE) who provides the overall technical support and management of the contract.
- Regional Coordinator—U.S. EPA employee with OWPE who coordinates enforcement activities with a Region, OWPE and the Department of Justice (DOJ).
- Regional Contact—U.S. EPA employee in the Regional Office who coordinates TES enforcement activities for the Region.
- Primary Contact—U.S. EPA employee responsible for initiation and monitoring of an individual work assignment.
- Program Manager—Contractor employee responsible for overall TES program operations.
- Work Assignment Project Manager—Contractor TES team member responsible for planning, management and execution of the services requested by U.S. EPA.
- Technical Monitor—Contractor employee responsible for technical work output of TES subcontractor team members assigned by Program Manager.
- Contracts Manager—Contractor employee responsible for all contractural and financial issues associated with the execution of the TES contract.

ADMINISTRATIVE PROCEDURES FOR PROCESSING WORK ASSIGNMENTS

At the beginning of each fiscal year the CERCLA and RCRA



Figure 1 Work Assignment/Work Plan Approval Process

programs plan what activities should be accomplished in that year and what mechanisms to use.

If the contract vehicle needed is determined to be an existing TES contract, the procedure begins using all the above-mentioned key personnel. The flow of the administrative procedures is shown in the Work Assignment/Work Plan Approval Process flow chart.

FUTURE CONTRACTS

To be discussed at the Conference.

OTHER CONTRACT VEHICLES

To be discussed at the Conference.

Contracting in the Superfund Removal Program

James Jowett Linda Garcynski U.S. Environmental Protection Agency Emergency Response Division Washington, D.C.

I. Background

- A. The Superfund Removal Program
 - 1. Scope 1980-1985
 - 2. Scope 1986-future
 - a. Effects of Revised National Oil and Hazardous Substances Contingency Plan
 - b. Effects of Superfund Off-site Disposal Policy
 - c. Effects of RCRA Land Disposal Regulations
 - and Use of Alternative Technologies
 - 3. CERCLA Reauthorization
- II. Overview of Contracting Efforts for the Removal Program
 - A. Technical Support
 - 1. 1980-1983
 - 2. 1983-1986
 - 3. 1986-1990
 - **B.** Cleanup Services
 - 1. U.S. Coast Guard Basic Ordering Agreements for Clean Water Section 311 Responses
 - 2. Notice to Proceed Contracts for CERCLA Activities
 - 3. Emergency Response Cleanup Services Contracts a. 1983-1986
 - b. 1986-1990
 - 4. Regional-Specific Cleanup Contracts
 - a. Mini-ERCS
 - b. Media or Site-Specific Contracting
 - 5. State-Lead Removals via Cooperative Agreements
 - 6. Other Contract Types
- III. Contract Features
 - A. Technical Assistance Team (TAT) Zone Contracts
 - 1. Statement of Work
 - a. Management
 - b. Prevention
 - c. Contingency Planning
 - d. Training
 - e. Community Relations
 - f. Emergency Response
 - g. Special Projects
 - h. Analytical Support
 - 2. Structure of Contract
 - a. Cost Reimbursable
 - b. Provisions for Award Fee
 - B. Emergency Response Cleanup Services (ERCS)
 - 1. Statement of Work
 - a. Management
 - b. Containment
 - c. Cleanup and Disposal d. Restoration
 - e. Analytical
 - f. Response Times
 - g. Equipment, Material, Labor Lists
 - h. Geographic Coverage
 - i. Capacities

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- 2. Structure of Contract
 - a. Time and Materials, Indefinite Delivery
 - b. Provisions for Award Fee

U.S. EPA SUPPORT CONTRACTS

c. Subcontracting

- d. Daily Cost Documentation
- e. Equipment Costs
- C. U.S. EPA Management Structure
 - 1. Contracting Office Contracting Officers
 - a. Centralized Operation
 - b. Negotiating and Writing of Initial Contract
 - c. Obligation Authority
 - d. Administration of Contract
 - 1) Modifications
 - 2) Invoice Audits
 - 3) Definitization of Delivery Orders
 - 2. Program Office Project Officers
 - a. Differences Between Headquarters and Regional Project Officers
 - b. Project Officer Duties
 - 1) Developing Procurement Packages
 - 2) Monitoring Performance
 - 3) Invoice Certification
 - Management Reviews of Regions and Contractors
 - 5) Overall Technical Management and Direction
 - 6) Coordination with Other U.S. EPA and Federal Offices
 - 7) Review of Key Personnel Qualifications
 - 8) Coordinate Use of Multiple Contracts or Use of Contracts in Multi-Region Zones
 - 3. Regional Office Deputy Project Officers
 - a. Issue Technical Direction Documents for TAT
 - b. Compile Performance Evaluations of Contractors
 - c. Recommendations for Award Fees Based on Performance in Region
 - d. Approval of TAT Special Projects
 - e. Monitoring Overall Contractor Costs for Region
 - f. Ensuring Contractor Follows Correct Management Procedures
 - g. Reviewing Contractor Deliverables
 - h. Oversees OSC Use of Contractors
 - i. Authorizes TAT Analytical Services
 - j. Responds to Headquarters Findings on Management Reviews
 - k. Oversees Contractor Management of Government-Furnished Equipment
 - 4. Regional Office On-Scene Coordinators
 - a. Regulatory Roles NCP
 - b. Contract Field Roles
 - 1) Ordering Officer
 - 2) On-site Direction
 - 3) Daily Cost Monitoring
 - c. Performance Monitoring
 - 1) Certification of Contractor Progress
 - 2) Tracking Costs Against Project Ceilings
 3) Developing Documentation on Contractor Performance
 - 4) Certification of Site-Specific Invoices
- IV. Future of Contracting in the Removal Program
 - A. Future of Zone Structure B. Scope of Future Contracts

C. Indemnification

ABSTRACT

The paper outlines developments in the Superfund removal program that have affected the way the program contracts for hazardous waste technical and cleanup support services. The development of the Technical Assistance Team contracts and the Emergency Response Cleanup services contracts is discussed. The paper then addresses how the agency manages removal contracts. Finally, the future of removal program contracts is described.

INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) was enacted in December 1980, and was recently reauthorized by Congress and signed by the President on October 17, 1986. Commonly referred to as Superfund. this act established a trust fund to clean up abandoned or uncontrolled hazardous waste sites. The new trust fund, \$8.5 million over the next five years, may be expended on two kinds of response actions: short-duration removal actions are authorized where immediate actions must be taken to address releases or threats of releases of hazardous substances requiring expedited response; longer-duration remedial actions are authorized to reduce releases of hazardous substances that are serious, but not immediately life-threatening. All Superfund responses are conducted according to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). This paper focuses on contracting in U.S. EPA's removal program.

Removal actions are short-term actions that stabilize or clean up an incident or site which presents a threat to human health or the environment. Such situations often involve fires or explosions, direct human contact with a hazardous substance or contamination of drinking water supplies. Typical response actions include removing and disposing of hazardous substances, temporarily relocating residents and controlling public access of people to a hazardous waste site. Superfund originally limited removal actions to six months in duration and \$1 million in total cost. The new legislation has raised these limits to 12 months and \$2 million. Exemptions to these limits may be granted, if appropriate. To date, 805 removal actions have been conducted under Superfund by U.S. EPA at a cost of approximately \$172 million.

SCOPE OF THE REMOVAL PROGRAM AND CONTRACTING --- 1986-FUTURE

By 1984, the agency had gained experience in the implementation of its removal and remedial programs. The 1982 NCP, while providing a good framework for the Superfund program, required a reassessment based on the experiences of the subsequent two years. One of the major changes made in the removal program was the combination of the three categories of shorter term response actions: immediate removals, planned removals and initial remedial measures, into a single category: "removals." Because all three response categories of activities had similar scopes of work and timeframes, it was believed that consolidation would enable the Superfund program to accomplish more of these removal actions with fewer regulatory hurdles. In February 1985 this consolidation was formally proposed. Its economic impact was assessed and was determined to be minimal. In November 1985 the NCP amendments were published as a final rule and became effective in February 1986.

These regulatory changes caused the removal program to begin reassessing the mode of contracting currently in use. Utilizing broad umbrella-type time-and-materials cleanup contracts was determined to be inappropriate for some types of actions in this new broad category of removals. Actions which allowed some period of planning, albeit short, prior to initiation might lend themselves to site-specific fixed price, or contaminant or mediaspecific cost reimbursement types of contracts. As discussed later in this paper, several significant changes were made in the contracting methodology for the removal program.

In addition to regulatory changes, significant policy changes have taken place during the last two years. The Superfund program made a commitment to comply to the extent practicable, with other applicable or relevant and appropriate environmental standards and regulations. For the case of off-site disposal of hazardous substances, this required that materials be sent to licensed facilities in compliance with the Resource Conservation and Recovery Act (RCRA) or the Toxic Substances Control Act (TSCA). Facilities accepting CERCLA waste must have been inspected and determined to be acceptable within six months of the time of disposal. Implementation of this policy requires a site-bysite determination by the On-Scene Coordinators (OSC) and their RCRA or TSCA counterparts that the chosen off-site facilities are appropriate for disposal and that the necessary permits would be obtained.

Also developed in conjunction with this policy is the RCRA program's phased development of land disposal restrictions or "land ban" regulations. This program prohibits disposal of certain hazardous wastes in land disposal facilities, causing the removal program to focus on the use of on-site alternative technologies to supplant land disposal.

CERCLA REAUTHORIZATION

Several significant changes to the 1980 CERCLA are contained in the reauthorization legislation. The expanded statutory limits may result in broader actions than those performed under the former \$1 million and 6-month limits. Contracting will change to respond to these higher cost, longer response actions. Removal actions, where appropriate, must also contribute to the efficient performance of remedial actions; a waiver provision allows removals to exceed the \$2 million, 12-month ceiling if the removal action to be taken is considered to be consistent with the remedial action ancitipated for the site. These provisions have major effects on the future methods of contracting used by the removal program.

CERCLA reauthorization provides that a response action contractor will not be liable under CERCLA or any other federal law for any damages which result from a release or threatened release of a hazardous substance, except if the release is caused by the contractor's negligence, gross negligence, or intentional misconduct. While this precludes the application of strict liability under federal law, it does not preclude state laws from subjecting response action contractors to strict liability. CERCLA reauthorization also provides the federal government with discretionary authority to hold harmless and indemnify a response action contractor against any liability for damages that result from a release of a hazardous substance caused by the contractor's negligence.

The reauthorized CERCLA also includes a rider that amends Subtitle I of RCRA and creates a trust fund for responses to leaking underground storage tanks. Although the leaking underground storage tank program will primarily be a state-led effort, it is envisioned that some limited federal presence will be necessary for major public health emergencies. Because the removal program is experienced in emergency response, emergency responses to underground tanks may be conducted using the removal program and its contractors.

OVERVIEW OF CONTRACTING EFFORTS FOR THE SUPERFUND REMOVAL PROGRAM

Successfully implementing emergency responses to releases of

hazardous substances requires extensive technical and cleanup services in support of the federal On-Scene Coordinators (OSC). Lacking the in-house resources to provide these essential services, U.S. EPA has acquired technical assistance and cleanup support through a network of contractor resources.

Technical Assistance

OSCs are provided technical assistance through the "Technical Assistance Team (TAT) Contracts for Emergency Response, Removal and Prevention." These contracts provide full-time technical personnel in specified professional disciplines. At the direction of U.S. EPA, TAT personnel provide a wide variety of technical support services, including prevention, contingency planning, training, response monitoring, response documentation and analytical support.

The first TAT contract was awarded to Ecology and Environment, Inc. on April 10, 1979, for limited support of the oil spill prevention and emergency response program under Section 311 of the Clean Water Act. Eleven TAT offices were established to support each U.S. EPA regional office and the Environmental Response Team (ERT) in Edison, N.J. These offices were staffed by a total of 32 TAT personnel. With the enactment of Superfund in December 1980, new work initiatives involving releases of hazardous substances imposed a substantial additional workload on the emergency response program. Accordingly, the agency upgraded the TAT contract to provide response support at hazardous waste sites. By the end of the original TAT contract in December 1982, TAT was staffed by 112 technical personnel in 32 professional disciplines.

A successor TAT contract was awarded to Roy F. Weston, Inc. in October 1982. This contract established 20 TAT offices supporting numerous U.S. EPA facilities, and provided the full range of technical services required to support the Superfund removal program. Reflecting an increase in Superfund activities, TAT contract staff grew from 112 to 198 full-time personnel. By the end of the Roy F. Weston, Inc. TAT contract in January 1987, over 13,000 technical assistance tasks will have been performed at a cost of \$50 million.

In anticipation of an expanded Superfund removal program due to CERCLA reauthorization, the agency is continuing to upgrade the capabilities of the TAT program. The successor to the Roy F. Weston, Inc. contract is being procurred under two separate TAT contracts. One contract (Zone 1) will provide TAT services in U.S. EPA Regions I through V, ERT and headquarters. A second contract (Zone 2) will provide TAT services in Regions VI through X. These contracts provide initial TAT staffing of 235 people, with provisions for permanent annual growth and optional temporary personnel increases. The contracts also expand the scope of support services, including limited emergency response implementation, RCRA and TSCA inspections, miniremedial investigations and enhanced analytical support. It is anticipated that the TAT zone contracts will be able to accommodate an expanding removal program through 1990.

Cleanup Services

In addition to technical assistance, OSCs require equipment, materials and personnel to physically remove and dispose hazardous substances. This cleanup support is provided through several contractual mechanisms.

As an interim measure, U.S. EPA implemented Notice to Proceed (NTP) emergency procurement procedures in 1981 to obtain cleanup services. Two hundred seventy NTPs were issued at a cost of over \$45 million. NTPs were preliminary contractual documents awarded by OSCs and meant to be replaced by definitive contracts negotiated by U.S. EPA Contracting Officers (COs). While NTPs were effective in obtaining timely cleanup services at removal sites, they had several drawbacks. Contractors were not under any pre-negotiated obligation to provide cleanup services, so cleanup arrangements were made on a site-by-site basis. NTPs were awarded non-competitively; and, U.S. EPA did not generally negotiate contract rates until performance under the NTP was complete, placing the CO at a disadvantage when negotiating final rates and terms of the NTP.

In 1983 and 1984, U.S. EPA awarded four Emergency Response Cleanup Services (ERCS) zone contracts, supplanting the NTPs. Zone 1 was awarded to O.H. Materials, Inc., and provides cleanup services in Regions I-III; Zone 2 was awarded to HAZTECH for Region IV. Zone 3 was awarded to PEI for Region V; Zone 4 was awarded to Reidel Environmental Emergency Services for Regions IV-X. The ERCS zone contracts provide an indefinite quantity, of specific services, equipment and materials during the contract period. Each contract ensures that U.S. EPA will order a stated minimum quantity of services, and that the contractor will furnish the minimum and any additional quantities, not to exceed a stated maximum. To date, these contracts have provided cleanup services for 472 responses at a cost of over \$112 million.

During the next two years, U.S. EPA will increase the number of ERCS zone contracts. Many of these contracts will provide cleanup services to only one U.S. EPA Region, as opposed to multi-regional coverage. It is anticipated that this approach will enhance competition and accommodate an expanded removal program due to CERCLA reauthorization.

U.S. EPA is also awarding several separate ERCS contracts to provide the regions with additional contractor resources to conduct removal actions. Like the zone contracts, each ERCS regional contractor will be responsible for both response-related and program management-related services. The Statements of Work for the zone contracts and regional contracts are essentially identical; however, the regional ERCS contracts generally will require fewer resources, smaller geographic coverage and less stringent response times.

In addition to ERCS regional contracts, U.S. EPA will pursue media or site-specific contracts when appropriate, particularly when specific removal activities are conducted on a recurring basis in a specific geographic area of the country. Missouri dioxin cleanup contracts in Region VII exemplify this situation. When site characteristics are well defined and sufficient time is available, U.S. EPA will compete site-specific, fixed price contracts. Media or site-specific contracting allows U.S. EPA to obtain more accurate contract rates and enhance overall competition.

Since the revised NCP consolidated removals, the agency considered developing cooperative agreements with states to conduct removal actions. States had conducted initial remedial measures under cooperative agreements during the years prior to the recent NCP amendments and there was no desire to eliminate this opportunity for state participation and responsibility. A work group is currently developing guidance for states to conduct non-time critical removal actions (i.e., removal actions can be deferred 6 months or more) at both National Priorities List (NPL) and non-NPL sites under cooperative agreements.

In addition to the changing structure of removal program contracts, a policy decision was made to allow use of remedial program contracts or state-led contracts for conducting certain nontime critical removal actions. These actions, known as expedited response actions (ERAs), consist primarily of actions previously identified as initial remedial measures. Site-specific subcontractors for these responses will be procured under the remedial contracts on a sealed-bid, fixed price basis. Another paper entitled "EPA's Expedited Response Action Program," presented at this conference, provides greater detail on ERAs.

CONTRACT FEATURES

Emergency Response Cleanup Service Contracts (ERCS)

The current ERCS contracting structure is undergoing recompetition. The four zone structure remains unchanged and the scope of the recompeted contracts remains similar to that of the current contracts. Minimum and maximum amounts of cleanup services are to be ordered under indefinite quantity, indefinite delivery provisions.

The contractors supply all personnel, materials and equipment specified in the Delivery Order to conduct removal actions. In addition, the new contracts will permit support for responses to leaking underground storage tanks to be conducted. Support is to be available to the OSC or other federal agent on a 24-hours per day basis.

An elaborate structure of response time requirements is specified in the contracts, which will ensure that the agency has complete national coverage in the event of an emergency; any delay in mobilization might place the public health at significant risk. Stringent response times are not necessary for all removal actions, but coverage must be available at all times for the "classic emergencies." Historically, 11 to 15 percent of all removal actions are classic emergencies.

Each contract has a zone program manager (ZPM) and staff to ensure that the scope of work is being implemented and that response time requirements are being met. The ZPM oversees the hiring and distribution of cleanup personnel, maintains cost records for all responses, manages the submission of required reports, manages the quality assurance program, and ensures that all administrative tasks are implemented. The ZPM is the key focal point for communication with the agency.

Each site response is assigned a response manager. The response manager oversees implementation of the site-specific response under the Delivery Order and works directly with the OSC in conducting cleanups. All ERCS contractor activities on-site are subject to the supervision of the response manager.

The ERCS contractor negotiates hourly, weekly and monthly rates for equipment, personnel and materials. Equipment, materials and labor are listed with fixed or provisional rates based on the program's historical experience and the anticipated frequency of their use. The new ERCS contracts will change the approach to certain previous fixed rate items, requiring them to be included as overhead charged to the agency instead of as a direct charge to the agency. Rates lists are constantly being refined based on the agency's historical uses of equipment and personnel.

One key element of the new ERCS contracts is the subcontracting of transportation and disposal. Previously, all transportation and disposal services were subcontracted. Under the new contracts, the OSC will be permitted to use the prime contractor for transportation activities costing up to \$5,000, based upon the OSC's best professional justment that using of the prime will be more cost-effective than using a subcontractor. For all activities related to transportation and disposal, the CO may waive the subcontracting requirement, enabling the prime to provide transportation or disposal services. The OSC must determine that the costs quoted by the prime are the appropriate choice in relationship to bids by potential subcontractors, and that no conflict of interest will occur by using the prime for transportation or disposal.

The contractor is also responsible for analyzing contaminated materials to aid in determining appropriate disposal or other response measures. The turn-around required for samples analysis is frequently very short due to the urgency of the situation. U.S. EPA's contract laboratories are generally unable to supply the quick turn around analytical services required; therefore, ERCS must provide this service.

A significant change to the contract structure is the addition of an award fee. The previous contracts provided only incentive fees. As the award fee is implemented, contractor efficiency and effectiveness will be evaluated, with the fee based on this evaluation. The agency expects that this award fee, which will also replace the previous handling charge for subcontracting, will be the primary motivation in improving contractor performance.

Subcontracting support will be reimbursed to the prime contractor at cost. A list of items not allowable as direct costs to the contract has been developed; other items have been listed which will not be paid for at fixed rates, but for which the contractor will be reimbursed at cost. Other improvements to the provisions, such as holiday and overtime pay, have been added. All costs will be logged on a daily cost tracking sheet which the OSC must verify. U.S. EPA has developed a software system to aid the OSC in tracking costs and is encouraging the contractors to use the system. The agency plans to look at requiring cleanup firms to develop accounting systems that document all charges based upon cost.

The future ERCS contracts will be augmented by the regionalspecific ERCS or mini-ERCS contracts, as well as site-specific or contaminant/media-specific contracts. The agency anticipates further diversification of the contracting structure as time allows.

Technical Assistance Team (TAT) Zone Contracts

The TAT contract provides technical support to OSCs for response to releases of oil and hazardous chemical substances.

Each TAT zone is managed by a ZPM. The TAT ZPM is the single point of contact with the U.S. EPA Project Officer (PO) and CO, and is responsible for: planning and executing all efforts performed under the contract; managing and supervising TAT Leaders; preparing and submitting required requests; monitoring all contractor costs; managing property; and ensuring overall quality control. Within each TAT zone, each office is managed by a TAT Leader (TATL). This individual is the single point of contact with the regional EPA Deputy Project Officer (DPO). The TATL has overall management and supervisory responsibility for team members. The TATL also receives and implements technical direction issued by the DPO; ensures that all quality assurance and chain-of-custody procedures are met; maintains all records; obtains any special services not available from within a TAT office; provides for rapid turn-around laboratory analysis; develops and implements team and site safety plans; and maintains a 24-hour, 7-day-a-week response capability.

Prevention activities performed by TAT usually involve nontransportation-related facilities that produce, refine, store and distribute oil and hazardous substances. TAT activities also include conducting facility surveys and inspections under the Spill Prevention, Control and Countermeasures Program, assists the OSC in preparing Notices of Violation for violations detected during inspections, and documenting cases. Planning activities are also taken by the TAT to prepare and review federal, regional, state and local emergency response contingency plans.

Other TAT activities include: training of EPA, state, local and contractor emergency response personnel in response procedures such as personal safety, data systems, decontamination and community relations; providing media relations support, such as arranging news conferences, distributing news releases and developing fact sheets; performing minor hazardous waste release containment efforts not exceeding \$1,000 in cost such as emergency pumping and sorbent booms deployment; obtaining special projects for equipment, services and personnel, studies not routinely available on the TAT, such as renting aircraft or allterrain vehicles, providing temporary housing for evacuees, or providing expert witnesses. The TAT contract also provides rapid turnaround laboratory or field analysis by collecting, storing, transporting, analyzing and disposing samples.

The TAT zone contracts are Cost-Plus-Award-Fee (CPAF) contracts which pay the contractor the actual allowable cost incurred in performing required work up to the estimates of total costs established in the contract, a fixed, base amount fee which does not vary with performance, and an award pool distributed based on subjective evaluation by U.S. EPA of the contractor's performance. Performance measures consider the areas of project planning, technical competence and innovation, scheduling and cost control, reporting, resource utilization and overall effort.

EPA Management Structure

Contracting Office - Contracting Officers

U.S. EPA's contracting office, the Procurement and Contracts Management Division (PCMD), centralized in headquarters, has the authority to develop requests for proposals (RFPs) or invitations for bid (IFBs) in accordance with the Federal Acquisition Regulations (FAR). For contracts in the removal program, project officers in the Emergency Response Division (ERD) develop a technical statement of work; projection of needs that considers personnel, materials or equipment; an estimated budget; and technical evaluation criteria. Procedures for quality assurance and treatment of confidential data are also supplied by the program. PCMD takes this information and determines the appropriate contract vehicle to develop the IFB or RFP.

The Contracting Officer (CO) evaluates proposal information on cost, accounting and other contractual grounds; and the program office, with regional participation, evaluates technical aspects of the proposals. Negotiations with the proposer follow and, upon completion of these negotiations, the CO enters into the contract. At that point, the CO begins administration of the contract.

The CO may modify the contracts, close out delivery orders in the case of ERCS (i.e., definitization), resolve disputes with contractors regarding any terms, conditions or payments, and conduct audits of records to determine the accuracy of invoices. The CO serves as the final arbiter on issues concerning either the TAT or ERCS contracts.

Program Office - Project Officers

The headquarters Project Officers (POs) (or in the case of mini-ERCS, regional POs) serve as the final technical authority on the contracts. The POs develop technical information for the competition process and evaluate all proposals in conjunction with their regional counterparts. The POs also serve as technical consultants during negotiations.

The POs monitor contract performance, and serve as liaison between the OSC and the contractor when technical issues arise. The POs monitor costs, evaluate contractor performance for award fee recommendations and monitor expenditures against the contract ceilings. The POs also certify invoices for payment.

The POs perform in-depth management reviews of compliance with contract terms by the contractors, the regions and the OSCs. A formal report is drafted, comments considered and final findings developed. A copy of the findings is sent to the Office of the Inspector General.

The headquarters POs also act in a coordination role with other federal agencies. This may occur when other agencies wish to use U.S. EPA contracts, or when they begin developing contracts for their agencies.

The POs review and approve or reject key personnel to work within the contract. This effort entails reviewing of resumes and comparing qualifications to those required by the contract. The headquarters POs will also assist the regions in determining which among the ERCS, mini-ERCS or other contracts are the most appropriate for conducting the cleanup. This may involve consideration of conflict of interest issues.

In summary, the POs serve as a liaison between the contracting office and the regional offices, dispensing assistance on issues related to site-specific responses in the context of the requisite contracts, A PO may travel, attend meetings and seminars and provide training in this role, as well as performing day-to-day, routine aspects of the job.

Regional Office - Deputy Project Officers

In each U.S. EPA regional office, ERT and headquarters, Deputy Project Officers (DPOs) have program management responsibilities for planning, executing and controlling the use of the TAT and ERCS contracts. DPOs interface daily with TATLs and ERCS ZPMs. DPOs ensure that contractors in their region provide the OSC with all necessary technical and cleanup support required during emergency responses. Other DPO responsibilities include: providing technical direction and oversight; issuing Technical Direction Documents (TDDs); coordinating the regional performance evaluation process; implementing headquarters and regional contract management policies and technical guidance; receiving and reviewing all contractor reports, such as monthly status and financial reports, and receiving, reviewing and distributing monthly contractor invoices.

Regional Office - On-Scene Coordinator

The On-Scene Coordinator (OSC) is defined by the NCP as the federal official predesignated by U.S. EPA or USCG to coordinate and direct federal responses under Superfund. All TAT and ERCS technical and cleanup support services are performed under the control of, and in support of the OSC. While OSC responsibilities encompass a very broad range of emergency response activities, the OSC has some specific contract management functions. The OSC prepares the Delivery Order statement of work and estimates the project ceiling amount. The OSC also directs and monitors ERCS contractor activities, reviews and certifies ERCS invoices, evaluates ERCS contractor performance at the end of each Delivery Order and, if warranted, prepares ERCS incentive award nominations.

The OSC directs and oversees on-scene technical support services provided by TAT members. This includes requesting TAT support from the DPO, directing TAT activities during emergency response efforts and evaluating TAT performance on a quarterly basis.

The OSC must ensure that removal contractor costs are justifiable and adequately documented to substantiate removal decisions and expenditures. The OSC's role in contractor cost control includes: projecting funding and costs for ongoing ERCS Delivery Order and TAT TDDs; monitoring and verifying the quantities of ERCS cleanup equipment, materials and personnel used during removal actions; tracking contractor costs against project ceilings; and documenting contractor activities through the use of logs and work reports.

CONCLUSION: FUTURE OF CONTRACTING IN THE REMOVAL PROGRAM

Future of Zone Structure

As stated in previous sections of this paper, the scope of the removal program has greatly increased since 1980 and the passage of the original CERCLA. Changes in the new legislation will continue this trend. The contracting structure will consequently require further diversification to meet the needs of increased scope.

The Emergency Response Division and the Procurement and

Contracts Management Division are undertaking several initiatives. A possible division of the ERCS structure into smaller zones is being carefully examined, based on quantity and complexity of work in the various U.S. EPA regions.

Further assistance to OSCs for contract management is being reviewed. Additional mini-ERCS or site-specific contracts will be used where the need arises. The TAT contract level of support to the OSC will be increased, enabling the OSC to better control site activities, and engineering evaluations/cost analyses may be undertaken to better define solutions to cleanup problems on complex sites.

Scope of Future Contracts

The scope of future ERCS contracts will become more limited.

ERCS will primarily be used for conducting cleanups where site responses are needed in short time frames. Regional contracts will contain requirements for longer response times, and those sites where action can be delayed for a few months may be competed site-specifically using expedited procurement methodologies. In general, the removal program intends to more fully define the types of cleanup services required and to develop varying scopes of work and contract types to meet these needs without sacrificing protection of public health and the environment. In this way, the agency hopes to further stimulate market development of cleanup services to meet the continuing demands of the future Superfund removal program.

Improving and Implementing Superfund Contracting Strategies

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The U.S. EPA is currently evaluating its basic contract strategy and operational plans to perform Superfund activities, in anticipation of Superfund reauthorization requirements. It is evident that any reauthorization effort will most likely necessitate an overall increase in specific site-related investigations and cleanup actions. Specifically, this effort will require:

- Improving existing contract structures and existing contract management institutions
- Developing and implementing alternative contract structures and contract management institutions
- Identifying and escalating "institutional barriers" to an ap-

propriate level of management for resolution

- Reducing the level of operational "hand off" to ensure program responsibility and accountability
- Adapting the agency infrastructure to correspond to the change in contracting structures

The evaluation and modification of current contracting structures is necessary to improve the pace, quality and costeffectiveness of site cleanup actions, in response to the anticipated expanded scope resulting from Superfund reauthorization.

This paper will report on the progress of models being developed and policy decisions being made concerning sitespecific investigations and cleanup actions.

Addressing the Consultant's Liability Concerns

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ABSTRACT

The consultant's desire to provide engineering services in the hazardous waste field is tempered by its present difficulties in properly managing the liability risks inherent in hazardous waste work. Approaches to minimize the probability of potential catastrophic financial loss while providing the engineering services needed to clean up hazardous waste sites are discussed.

The problem is illustrated by the inability to obtain some types of liability insurance, higher deductible amounts, lower upper limits of coverage and substantially higher policy costs.

Tort reform is an essential but long-term approach to a rational resolution of the liability issue. Tort reform legislation already has been passed or is pending in a large number of states. Key categories in which the states are beginning to provide legislative relief include: limiting joint and several liability and placing a cap on damage awards, especially as applied to non-economic damage.

A majority of the litigation against consultants stems from alleged design error. Quality control programs are being expanded to address this area of concern.

Indemnification by the client provides a means of protecting the consultant from undue risk. Indemnification language developed by the American Consulting Engineers Council is suitable for hazardous waste contracts. However, many states have antiindemnification statutes that prevent a party from being protected against its own negligence. Therefore, caution should be exercised when contemplating the use of indemnification as a risk management tool.

INTRODUCTION

Unenlightened and often intentional disposal practices involving hazardous wastes have resulted in major environmental pollution. Extensive news media coverage of the problems caused by hazardous waste mismanagement continues to increase public awareness and support for the Superfund Program to clean up dangerous hazardous waste disposal sites.

It is axiomatic that the country's best interest is served by having the highest quality engineering talent heavily involved in analyzing and developing solutions to hazardous waste problems. To obtain engineering talent, it is essential that liability risk associated with involvement in hazardous waste work be manageable. Many consultants, fearing financial ruin, have not participated in hazardous waste cleanup due to the inability to adequately protect against the liability risk involved. Other consultants participating in hazardous waste work are investing substantial time and resources to minimize this risk. This paper discusses the methods of addressing the consultant's liability concern and identifies available techniques to manage the risk. The first step in identifying useful techniques for risk management is to gain a clear understanding of the problem. The initial section of the paper defines the nature and extent of the consultant's liability concern. The remainder of the paper is devoted to discussion of the potential risk management techniques which include:

- Captive insurer
- Tort reform
- Minimizing risk
- Indemnification by the client

PROBLEM DEFINITION

It is often said that a design firm's clients are its greatest asset. In recent times this truism has proved to be a double-edged sword. Between 40-50% of all claims have been brought against the design professional by his greatest asset—owners.

Although specific percentages vary from year to year, Table 1 gives an approximate breakdown of claims brought by various parties against design firms:

	Tab	le 1		
Breakdown of	Claims Filed	Against	Engineering	Firms

Claims Brought By	
Owners	40-50%
Contractors	20-25%
Other Design Firms	5-10%
Other 3rd Parties	25-35%

These professional liability claims can be analyzed also on the basis of cause. Table 2 shows this breakdown:

Table 2 Types of Claims Filed Against Engineering Firms

Claims Involving	
Personal Injury	15-25%
Design Error & Failures	50-60%
Contract Disputes	15-25%

Although the statistics shown in these tables can help focus claim reduction efforts in the most beneficial directions, the bare numbers do not explain the current professional liability insurance problem, especially in the area of hazardous and toxic waste work. Symptoms of this problem include: reduction of the number of firms offering professional liability insurance; increasing premium cost and reduction of coverages (in some areas, such as pollution claims, coverage has been completely eliminated); and increasing deductible limits.

The cause of the current problem results from the interaction of two disparate factors:

- Insurers' use of cash flow underwriting
- · Continued expansion of liability under U.S. tort law

In the recent past, high interest rates allowed insurers to use cash flow underwriting which utilizes investment income earned from premiums to make up for any difference between actual losses and premium income. However, once interest rates declined, investment income was insufficient to cover insured losses. The result was a predictable rise in the cost of insurance.

Although the expansion of tort liability is by no means taking a straight course, the general trend of our common law (judicial decisions) is toward compensating injured victims at the expense of insurance companies. This trend produces results which are unexpected and, hence, unfunded by insurers. The prospects of huge losses in cases such as Agent Orange, asbestos and other product liability suits have resulted in the insurance industry's complete withdrawal from the area of pollution damages for design professionals.

Whether insurance companies are partially responsible for the consultant's liability problems as well as the role they will play in providing solutions are controversial issues. It is not important here to judge the wisdom or integrity of the insurance industry, but rather to understand the impact of insurance, or lack thereof, on the consultant's liability dilemma.

The two types of insurance policies carried by most consultants are:

- Comprehensive General Liability
- Professional Liability

Comprehensive general liability provides protection against bodily injury and property damage claims which result from an occurrence as set forth in the policy. Professional liability insurance provides protection against errors, omissions and negligent acts which arise out of the performance of professional services. Professional liability insurance, until recently, was available from a significant number of carriers. The insurance industry problems have resulted in only two major carriers now offering professional liability insurance. These are:

- Design Professionals Insurance Company
- Victor O. Schinnerer & Company

The insurance industry has been plagued by poor financial performance in recent years. The March 10, 1986 issue of *Business Week* reported insurance industry losses in excess of \$2 billion in 1984, \$5 billion in 1985 and \$2 billion in 1986.

A recent survey sponsored by the American Consulting Engineers Council and other groups revealed the consequences of such a performance. Liability insurance rates for consultants increased an average of 48% last year. Higher deductible limits and higher insurance premiums reduce profitability; however, an even greater concern is the lower total coverage which can be obtained. This reduced coverage is caused by a withdrawal from the market by various reinsurers. (Reinsurers provide the excess layers of coverage above the primary policy limits.) The effect of the reinsurers' actions is a lack of protection against catastrophic loss.

For some perils such as asbestos and pollution-related losses, not even primary coverage is available. Since the 1960s, professional liability policies have been written on a claims made basis. This means the insurance company pays claims which occur during the policy period but will not pay claims which occur after the coverage is terminated. Therefore, even if a consultant had coverage for hazardous waste work at the time the work was performed, the consultant is now totally exposed under current policies. The pollution exclusion in current policies utilizes a very broad definition of pollution:

> Pollutants are defined as any solid, liquid, gaseous or thermal irritant or contaminant, including smoke, vapor, soot, fumes, acids, alkalis, chemicals and waste. Waste includes materials to be recycled, reconditioned or reclaimed.

The exclusion applies to claims or claim expense arising out of the actual, alleged or threatened discharge, dispersal, release or escape of pollutants.

It appears unlikely that insurance companies will provide coverage for pollution-related claims in the forseeable future. Paul Genecki is referenced in a May 1986 Engineering Times article as stating that a turnaround is not expected soon. He indicates that providing insurance for pollution claims would require several reforms including the following:

- Rescind application of the joint and several liability standard
- Clarify who owns pollution, both now and in the future
- Provide specific quantitative safety standards established by a federal agency. These standards must indicate what is and is not legally safe, both now and in the future.

If it is not possible to obtain adequate pollution insurance coverage, then other means of providing protection against potentially devastating claims must be utilized.

CAPTIVE INSURER

The inability to obtain coverage on work involving pollution has provided incentive to consider self-insurance pools or captive insurance companies. The concept has been implemented by the National Solid Waste Management Association for hazardous waste contractors. A similar approach has been seriously considered by the American Consulting Engineers Council (ACEC). The concept currently is being evaluated by the Hazardous Waste Coalition, a group of consulting engineering firms.

Tax laws influence the economic viability of forming captive insurance companies. Insurance premiums are generally tax deductible. However, a March 24, 1986, article in *Forbes Magazine* states that payments to self-insurance reserves are not tax deductible. The article notes that claims from a firm's self insurance reserves can be deducted, but only when the claims are actually made. Thus the Internal Revenue Service receives taxes on the interest earned by the reserves. The IRS position is being challenged and the Supreme Court will hear the case.

TORT REFORM

Tort can be defined as a violation of a right not rising out of a contract, or a private or civil wrong or injury. Under traditional tort law, the injured person is compensated only if the guilty party can be specifically identified. However, recent awards have been made to injured persons even when a specific party cannot be identified. The trend toward very large awards to injured persons has caused much concern. The situation has been described by Paul Wenske as follows:

> The civil court system is out of control, juries are runing amok and courts have fashioned new theories of liability that have turned the court system into an inefficient social welfare giveaway.

The other side of the argument has been described by a Kansas

plaintiff attorney as follows:

The corporate world is amoral. If it costs more to be safe than dangerous, they're going to be dangerous.

Regardless of the reader's perspective, the inefficiency of the existing tort system is disturbing. A Rand Corporation study indicates that in asbestos cases only about one-third of the total money goes to victims.

There is widespread belief that tort reform is needed. A Department of Justice study recommends the following reforms:

- Return to fault based standard for liability
- Require causation findings be based on scientific and medical evidence
- Eliminate joint and several liability in certain cases
- Limit non-economic damages (such as pain and suffering) to a reasonable amount
- Limit attorneys contingency fees
- Provide periodic (rather than lump sum) payments of damages for future medical care or lost income
- Reduce awards where compensation also will be made from other sources
- Encourage alternative dispute resolution methods to resolve cases out of court

The enactment of new legislation at both the state and Federal levels takes a massive effort by a large number of groups. One coalition of groups working to achieve tort reform at both the state and national levels is the American Tort Reform Association (ATRA). Associations that include large numbers of consultants as members and that are members of ATRA include the National Society of Professional Engineers, American Consulting Engineers Council, American Society of Civil Engineers and the American Water Works Association. The ATRA serves as an information clearinghouse for each member association.

Tort law has traditionally been controlled by state law. Approximately 95% of tort cases are tried in state courts. For this reason, much of the effort to reform tort law occurs at the state level. There is tremendous activity in tort reform as indi-

Table 3
Partial History of States that have Passed Tort Reforms

	Type of Action			
	Modifies or Limits	Cap on	Cuts	
State	Joint & Several Liability	Damage Awards	Insurance Premiums	
		\$		
California Colorado	X X	250,000 ⁽¹⁾		
Florida Kansas		450,000 Varies ⁽²⁾	x	
Maryland Michigan	x	350,000 ⁽¹⁾ 225,000 ⁽¹⁾		
Minnesota Missouri New Hampshire		400,000 ⁽⁴⁾ 350,000 ⁽³⁾ 875,000 ⁽¹⁾		
New York South Dakota Utah	x x	1,000,000 ⁽³⁾ 1,000,000 ⁽³⁾		
West Virginia Washington	x	1,000,000 ⁽³⁾ Tied to life Expectancy		

(1) Applicable to non-economic damage (i.e., pain and suffering)

(2) Medical malpractice-\$250,000; non-economic-\$1,000,000; limit for all losses-\$3,000,000.

(3) Medical(4) Intangible losses excluding pain and suffering

cated by the fact that more than one-half of the states are working on proposed legislation.

A substantial number of states have passed legislation which addresses tort reform. Table 3 contains a partial list.

In addition to the activity at the state level, there has been Federal involvement. A Tort Policy Working Group was established by the Attorney General and consisted of representatives from 10 agencies and the White House. The group issued a report in February 1986. The report noted the extraordinary growth of the number of tort lawsuits and the average award per lawsuit. The group concluded tort law is a major cause of the insurance availability/affordability crisis and also determined action by the Federal government was appropriate and necessary.

An example of proposed Federal legislation is the Litigation Abuse Reform Act (S. 2046). Provisions of the bill include limitations on damages for non-economic losses, contingency fee agreements and awards for punitive damages. The legislation would cover alleged negligence by consultants where damages are sought for physical injury or mental pain or suffering.

The effect of tort reform on the availability and cost of liability insurance for consultants is somewhat uncertain. Insurance industry spokesmen indicate that tort reform will expand the general availability of casualty/liability coverage. However, the most critical void in available coverage, pollution coverage, will not be resolved soon, even with passage of tort reform legislation at the state and Federal levels. An explanation for the limited impact of tort reform on consultants is stated by Stefan Jaeger in the June 1986 issue of *Engineering Times*. Jaeger's article states that only about 20% of damage claims paid on engineer's policies stem from personal injury suits. Most of the claims paid are the result of property damage and breach of contract suits. The damage and fee limit contained in tort reform legislation would not greatly reduce the claims paid in the property damage and breach of contract suits.

MINIMIZING RISK

Minimizing risk is an important part of the consultant's program to address the liability concern. Important elements of the concept include the following:

- · Evaluate types of work performed
- Execute a carefully written contract
- Provide quality control
- Document communications
- Use proven contract documents
- Understand and utilize the fundamentals of conflict resolution

The engineer must recognize and evaluate the tendency for certain types of work to lead to litigation. Traditional problem areas include services for dams and tunnels. Current concerns include asbestos removal and land disposal of solid and hazardous waste. Much of the concern involves uncertainty regarding future consequences. Will employees working on an asbestos removal project bring suit over alleged health problems 25 yr in the future? Will leachate from a land disposal site pollute a drinking water supply? In either event, the probability of insurance covering litigation costs and damage claims is remote. Thus, the consultant must understand the risks and implement strategies to limit risk to acceptable levels.

A key to minimizing the consultant's risk is to negotiate and execute well-written contracts for engineering services. The contract should clearly define the scope of services to be provided. Many problems can be avoided by ensuring that both the consultant and the client have the same understanding as to what will be provided to the client. Although many consultants tend to view the non-engineering portions of contracts as mere "boilerplate," failure to properly draft and review the entire contract with competent legal assistance can result in unexpected liability. Legal review and assistance during contract preparation should be standard practice on projects involving hazardous waste site cleanup.

Once a sound contract has been written, the consultant's attention should be devoted to providing high quality work products. Employing qualified personnel is a fundamental step in producing high quality work. Hazardous waste work requires specialists in the areas of hydrogeology, chemistry, industrial hygiene and engineering. Firms not having the required expertise on their own staff must utilize other consultants to supplement their needs. Personnel training and technology transfer also are essential. Hazardous waste cleanup techniques are rapidly changing and therefore new to many engineers. The skills required for hazardous waste cleanup services can be developed through attendance at meetings and seminars, reading the technical literature and communication with those knowledgeable in the field.

A basic element in quality control is review of work products by experienced personnel that are independent from the work product. Errors and omissions can be reduced greatly by independent reviews of reports, design memoranda, drawings and specifications.

Documenting communications should be a part of the consultant's program to minimize and control risk. All significant telephone calls and conferences should be documented in writing. Design memoranda outlining the approach to the project and major design parameters should be written early in the project and updated as needed. All key decisions and changes in agreements should be recorded. It is important that written communications not include cryptic, trite or cute notes or comments. These unnecessary or inaccurate comments may be difficult to explain to a jury in a subsequent lawsuit.

Periodic written progress reports are an effective means of documenting the sequence of events on any project. These written reports are especially important on projects which are suspended or restarted, or which have changes which occur during the life of the project.

Another element of good communication is timely response. Letters, shop drawings and other submittals should be processed and responded to in a reasonable time period.

Many of the claims against consultants result from activities during construction phase services. To minimize these claims, it is important to utilize carefully developed contract documents. The Engineers' Joint Contract Documents Committee (EJCDC) has developed a set of carefully integrated contract documents. Use of these contract documents allows a consultant to take advantage of the latest recommendations of the professional societies based on their continuing research and standardization.

Disputes and misunderstandings occur on all projects of significant size. All too often, minor differences of opinion burgeon into demands, and those demands escalate into formal claims. Without appropriate management, the filling of claims marks the beginning of lengthy, expensive litigation that culminates in arbitration or courtroom confrontation. It is extremely difficult to develop a rational strategy for concluding a dispute once enmeshed in legal proceedings. The dispute quickly becomes magnified to the point that the parties fail to consider alternatives that would benefit them. Claims and counterclaims often are significantly inflated above their realistic value; the parties may fail to consider litigation costs and the time value of money in their evaluations; and sources of compensation are frequently overlooked. By structuring construction contracts so that they can be readily administered and are flexible enough to address potential claims through administrative procedures, claims frequency can be minimized. Careful attention to the following subjects will minimize the potential for future claims:

- Contract modification procedures and dispute resolution mechanisms
- Risk-sharing provisions
- · Project constructibility and bidability
- Value engineering review

Effective dispute management requires an aggressive, innovative approach. Every effort should be made to resolve disputes at the earliest practical date.

INDEMNIFICATION

It is generally conceded that consultants are not responsible for the existence of most Superfund sites, therefore, the consultant should not incur excessive liability when providing engineering services for cleanup of the sites. Based on this premise, a mechanism is needed to protect the consultant. As discussed previously, insurance frequently is not a viable source of protection. An alternate approach which is being increasingly used is indemnification.

A committee of the American Consulting Engineers Council has developed language which can be used to provide indemnification to the consultant. The language suggested is as follows:

> "For services involving or relating to hazardous waste elements of the Agreement, Owner shall indemnify, defend and hold harmless Engineer and its consultants, agents and employees from and against all claims, damages, and employees from and against all claims, damages, losses and expenses, direct and indirect, or consequential damages, including but not limited to fees and charges of attorneys and court and arbitration costs, arising out of or resulting from the performance of the work by Engineer, or claims against Engineer arising from the work of others, related to hazardous waste."

> "The above indemnification provision extends to claims against Engineer which arise out of, are related to, or are based upon, the dispersal, discharge, escape, release or saturation of smoke, vapors, soot, fumes, acids, alkalis, toxic chemicals, liquids, gases or any other material, irritant, contaminant or pollutant in or into the atmosphere, or on, onto, upon, in or into the surface or subsurface (a) soil, (b) water or watercourses, (c) objects, or (d) any tangible or intangible matter, whether sudden or not."

Legal assistance is important when drafting indemnification language for a contract. An indemnification clause should be carefully drafted and should recognize the bargaining position of all parties to the contract. Numerous states have enacted some form of anti-indemnification statute. Indemnification tends to be inconsistent with the general premise that everyone should be responsible for his own errors. Thus, before the indemnification approach can be used successfully, it must be compatible with applicable state statutes. At least one state, New Jersey, provides by statute indemnification for consultants performing hazardous waste cleanup services.

CERCLA legislation was pending at the time this paper was being written. Therefore, no discussion is given to the contents of the legislation or the impact on consultants' services for superfund work. Adequate protection in the legislation for consultants providing services at superfund sites is critical. If the legislation authorizes a pass through of indemnification to state led superfund work, it will open the door to a substantial portion of the work being administered by state agencies.

Federal clients other than the U.S. EPA which manage haz-

ardous waste work include the Corps of Engineers, Department of Energy and Department of Defense. These agencies have directives and policies which cover the approach to indemnification. The adequacy of the indemnification provided must be analyzed carefully by the consultant on a case by case basis.

CONCLUSIONS

Consultant liability concerns must be resolved to assure the participation of technically qualified and financially responsible consultants in the hazardous waste cleanup program. The current insurance situation provides no coverage for pollution related claims. The insurance available is characterized by higher deductible amounts, lower upper limits on coverage and higher insurance costs.

Answers to the liability concerns are found in expanding quality control programs, obtaining indemnification from the client and passing tort reform legislation. Expanding the consultant quality control programs is essential since a majority of suits against consultants historically have been due to alleged design error. An important element in quality control is assuring that personnel utilized on hazardous waste projects have strong credentials in their areas of expertise.

The availability and costs of insurance for consultants involved

in hazardous waste work are interrelated with tort reform legislation. As state and Federal legislation is enacted, it is likely that insurance will be available from a larger number of firms, probably at more reasonable costs. However, tort reform is not expected to result in the availability of coverage against pollution related claims in the near future. In the absence of insurance for pollution related claims, indemnification by the client is necessary. The exact form of the indemnification will vary according to the type of client and nature of the work involved.

The absence of either insurance coverage or protection through indemnification will result in an unsatisfactory situation. Under these circumstances, the only consultants available to provide the services are firms willing to run the risk of bankruptcy when litigation occurs.

The firms willing to risk bankruptcy are not available in adequate numbers to provide needed services. In addition, a bankrupt firm offers no protection against financial loss to its former clients.

All of the solutions discussed will play a role in overcoming the liability problem. In the short term, indemnification must be a major factor in the consultant's ability to provide service. As tort reform becomes a reality and as the insurance industry returns to a more normal state, it is expected that increased coverage eventually will be available to consultants.

Federal Indemnification of Superfund Program **Response Action Contractors**

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ABSTRACT

The U.S. EPA currently is evaluating approaches to assist the Property & Casualty insurance industry's ability to provide prospective pollution liability insurance. The 1986 market for pollution liability insurance is minimal, is hampered by continuing capacity problems and is not expected to fulfill the present or future liability insurance needs of the hazardous waste management industry. Five Federal environmental statutes require those subject to the statutory law to furnish evidence of financial responsibility, thus a viable commercial liability insurance market is important to the achievement of Federal environmental policy goals.

Public policy decision-making regarding the use of commercial liability insurance in the hazardous waste management industry has become increasingly difficult in recent years because of rapid and unpredictable expansions and contractions in the supply, terms and conditions, and price of commercial liability insurance. The Congress, concerned about a withdrawal of response action contractors (RACs) from the Superfund program incorporated language into the existing CERCLA reauthorization bill authorizing the U.S. EPA to provide limited interim indemnification against liabilities for negligence to RACs on a discretionary basis. This paper briefly reviews the proposed U.S. EPA Superfund response action contractor indemnification program.

INTRODUCTION

One of the cornerstones of the Superfund Program under CERCLA has been the availability of gualified response action contractors (RACs). These contractors have developed into a unique industry specializing in addressing the nation's hazardous waste sites. Because of the hazardous contaminants managed at these sites and the uncertainty surrounding new response technologies, RACs face potential liabilities if a site releases new hazards during or after the remedial response. In the past, these contractors have relied primarily on a combination of commercial liability insurance and government indemnification to reasonably offset the liability risks (e.g., third-party suite) from Superfund program cleanup activities. However, the recent retreat of the commercial property and casualty (P&C) insurance industry from the pollution liability insurance market is threatening RAC withdrawal from the hazardous waste site business (1).

With the expected heavy load of site responses for the forthcoming years, any reduction in the capacity of the RAC industry may adversely affect the Superfund Program (2). Table 1 and Figure 1 summarize the potential RAC pollution liability issue. Table 1 lists the potential damages and the liability bases upon which suits seeking redress could be brought against RACs. Figure 1 displays the potential RAC pollution liability risk as a function of several key component parts consisting of the probability of occurrence, potential damages and the legal environment.

Table 1. Potential CERCLA Response Action Damages and Bases for Liability

Damages

- Compensatory Damages
 - A. Special Damages
 - I. Medical Care Expenses
 - 2. Loss of income
 - 3. Medical Monitoring
 - Tests
 - 4. Risk of Latent Disease
 - Carcinogenic
 - Mutagenic
 - Teratogenic
 - **B.** General Damages
 - 1. Pain and Suffering
 - - nate Water Supply
 - Business Interruption/
 - 5. Other Economic Values
- II. Punitive Damages
- III. Environmental/Natural
- IV. Environmental Right Damages **Cleanup** Costs
 - State, Local, County, etc.
- VI. Other Damages
- VII. Defense Costs

The Congress, concerned about a withdrawal of the RACs from the Superfund program, incorporated language into the existing CERCLA reauthorization bill authorizing the U.S. EPA to provide limited interim indemnification against liabilities for negligence to RACs on a discretionary basis. U.S. EPA indemnification will apply to all U.S. EPA approved RACs and their subcontractors working under the Superfund cleanup program for the U.S. EPA, another Federal agency, states involved in cleanups of CERCLA sites, and potentially responsible parties (PRP). These provisions, if enacted, will represent an important development in the distribution of the risks from discharges of hazardous substances managed at Superfund sites. In essence, the Federal government will be stepping temporarily into the private sector as a surrogate



A. Common Law

- 1. Negligence
- 2. Strict Liability
- 3. Trespass
- 4. Nuisance
- Statutory Liability 1. State
 - 2. Federal
- 2. Mental Anguish 3. Loss of Consortium 4. Disfigurement C. Property Damages 1. Loss of Property Values 2. Relocation Expenses Temporary Housing

Permanent Housing

- 3 Procurement of Alter-
- Extra Expenses

Resource Damages



Figure 1 Response Action Contractor Liability Function

insurer. This direct interim substitution or supplement of commercial insurance will significantly ensure the nation's technical ability to remedy uncontrolled hazardous waste sites.

PROBLEM SUMMARY

During the first 5 yrs of the Superfund Program, RACs who participated in the program by working for the U.S. EPA were provided with Federal indemnification in excess of a \$1 million liability insurance policy or self-insurance layer (for third-party liability and cleanup costs) except in cases that involved gross negligence. During the course of the recent CERCLA reauthorization debate, it became apparent to the U.S. EPA, Congress, and RACs that the commercial liability insurance industry was no longer willing to provide affordable and adequate liability insurance coverage to RACs involved in the Superfund cleanup program.

The insurance industry, suffering from record underwriting losses and capacity problems during 1984 and 1985, withdrew from many high risk liability insurance lines (e.g. pollution liability). The Property & Casualty (P&C) insurance industry argued that it could no longer underwrite pollution liability insurance because of (1) a lack of capacity and reinsurance support, (2) a lack of loss data, (3) no existing uniform risk analysis methods (4) expanding tort liability in the U.S. legal system, (5) real and anticipated losses and (6) a general societal perception that hazardous waste cannot be safely managed.

During the CERCLA reauthorization debate, RACs argued that without viable risk transfer mechanisms, such as commercial liability insurance or government indemnification, they would be forced to withdraw from the Superfund cleanup program, rather than subject their limited corporate assets to potential Superfund liabilities. RACs viewed the existing Federal government indemnification program under Superfund to be inadequate because; (1) there is an absence of statutory authority to indemnify RACs, (2) there is no source of funds identified by statute, (3) it may violate the Anti-Deficiency Act, and (4) it did not apply to all parties (e.g., RACs working for other Federal agencies, States or responsible parties). The RAC community introduced several legislative proposals to address the lack of adequate risk transfer mechanisms for Superfund related RAC liability including: (1) statutes of limitations/repose, (2) liability caps, (1) a negligence liability standard for RAC and (4) mandatory government indemnification for all

RAC Superfund cleanup program liability.

The U.S. EPA and Congress realized that a lack of viable risk transfer mechanisms for the RAC community might cause prudent, qualified RACs to withdraw from the Superfund cleanup program and could lead to delayed and reduced quality Superfund cleanups in the future, if the hazardous waste management industry, such as the Superfund RACs, pulls out of the hazardous waste cleanup market, the cost of the shortage in pollution liability insurance coverage ultimately is borne by the public. The Superfund program is especially vulnerable to this withdrawal because a delay in response action or use of unqualified contractors may pose direct risks to public health and the environment. The U.S. EPA, after extensive study of the P&C insurance industry, realized that adequate RAC commercial liability insurance might not be available on a stable basis for several years. In an effort to solve this problem, the U.S. EPA supported legislative proposals that would provide the U.S. EPA with interim discretionary indemnification of RACs to reasonably offset liability risk associated with Superfund cleanups. The U.S. EPA also supported legislative proposals that sought a pre-emptive and uniform negligence liability standard for RACs and a modified version of the Risk Retention Act (which allows RACs to provide themselves with self-insurance through risk pooling and captives).

Both Superfund bills contained provisions for the U.S. EPA to indemnify RACs. After considerable debate, Congress agreed in conference to adopt the language into the final CERCLA reauthorization bill authorizing the U.S. EPA to provide limited interim indemnification against liabilities for negligence to RACs on a discretionary basis. In addition, Congress agreed in conference to adopt a Federal non-pre-emptive negligence standard for RACs and a modified version of the Risk Retention Act.

RATIONAL FOR FEDERAL GOVERNMENT INDEMNIFICATION

The primary thrust underlying the Government's indemnification of Superfund RACs is the goal of pushing ahead with Superfund cleanups. This goal assumes the availability of high-quality cleanup contractors for all phases of the program (i.e., site investigation, risk assessment, response selection/design and construction). Providing the U.S. EPA with the authority to provide discretionary indemnification to RACs essentially calls for the Agency to become a surrogate insurer until the P&C insurance market condition changes favorably. Federal government intervention in the marketplace for RAC liability insurance is justified for several public policy reasons including (1) discretionary indemnification is an interim vehicle designed to keep the Superfund cleanup program operative until the private sector insurance market is able or willing to provide adequate and affordable liability insurance for RACs working in the Superfund program, (2) discretionary indemnification of RACs does not create a permanent Federally intrusive insurance program, which could discourage the private sector insurance industry from participating prospectively, (3) discretionary indemnification provides RACs with performance incentives by not providing for all liability expenses (i.e., deductibles and limits) and (4) discretionary indemnification is consistent with Administration concerns and Congressional intent.

In addition, such temporary Federal government intervention is justified given the inherent problems in the P&C insurance marketplace including: (1) the P&C underwriting cycle has traditionally produced periods of either excess demand or excess supply for insurance coverage, (2) state regulation of the insurance mechanism discourages new firms from coming into the marketplace during periods of low P&C insurance availability and (3) the P&C insurance industry has high entrance barriers in terms of capital requirements, thus limiting the number of firms that can meet the capital reserve requirements. These aspects constrain the P&C industry from responding quickly to demand for insurance during periods of low insurance availability and excess demand.

The renewed surge in the use of offshore captives has shown that only when exempted from state regulation and when backed by numerous large firms can new insurance entities emerge in response to excess demand. A modified version of the Risk Retention Act (contained in both the House and Senate Bills and adopted in conference), allows for expedited and efficient formation of selfinsurance through risk pooling by hazardous waste industry members (including RACs). Risk pooling should provide additional risk transfer mechanisms for RACs Superfund cleanup liability in the absence of adequate and affordable commercial liability insurance.

Instead of waiting for the insurance industry to realign itself to RAC demand for liability insurance, the U.S. EPA and Congress determined that the cost of slowing down the Superfund Cleanup program warrants temporary intervention into the insurance marketplace (through RAC indemnification) and long-term promotion of alternative risk transfer mechanisms (through captives, self-insurance pools, etc.).

HOW THE U.S. EPA WILL USE ITS DISCRETIONARY INDEMNIFICATION AUTHORITY

If enacted, the U.S. EPA RAC indemnification program will apply to all U.S. EPA-approved RACs and their subcontractors working under the Superfund cleanup program for the U.S. EPA, another Federal Agency, the States and PRPs. As mandated by Congress, the U.S. EPA will offer indemnification to a RAC working in the Superfund program only if two conditions are met. First, the RAC must make every reasonable attempt to obtain adequate liability insurance and/or responsible party indemnification. The U.S. EPA will require any RAC receiving indemnification to continue to attempt to obtain insurance and/or responsible party indemnification throughout the life of the contract. If liability insurance and/or responsible party indemnification is made available during the life of the RAC contract, the U.S. EPA will have the discretion to require that such insurance and/or responsible party indemnification be obtained and may reduce the terms of the indemnification agreement accordingly. Second, the U.S. EPA must determine that liability insurance or responsible party indemnification is not available, is not adequate to offset the RACs liability risk and/or is not reasonably priced. If these two conditions are met, the U.S. EPA will offer indemnification only as a supplement or substitute for insurance or responsible party indemnification, including limits and deductibles, and only for liability related to releases of hazardous substances resulting from RAC Superfund cleanup activities. Figure 2 summarizes the proposed sharing of CERCLA response action pollution liability risk between RACs, P&C insurers, responsible parties and the U.S. EPA.

U.S. EPA indemnification of RACs, including all specified terms and conditions, will be offered to the lead (prime) RAC. The indemnification will be made available by the lead RAC to any U.S. EPA authorized subcontractors with which the lead RAC may team. The U.S. EPA will retain the right to control the defense and set-

	TADA OF 14	tênêc tes	
RAC (Negli	RAC Gross Negligence	Layers of Liability in Cases of RAC Negligence	Risk Handling Mechanism
	Unlimited	Potential RAC Unlimited Liability Layer	Risk Retention
Dollars of Loss	Linbility (risk retention)	EPA Indomnification Layer (Subject to Limits and Deductible Levels)	Risk Transfer
		Responsible Party Liability Layer (e.g., Indemnity Agreements)	
		Available Commercial Property & Casualty Insurance Layer	
		RAC Deductible Layer	Risk Retention

Type of Negligence

tlements of a claim covered by RAC indemnification. Since the source of indemnification funding is now identified by statute, it will allow the U.S. EPA to establish comprehensive processing procedures for the reimbursement of defense costs and claims. The limits of indemnification will be determined based on what is sufficient to offset RAC liability risk, and not by what is or has been available in the commercial liability insurance market.

U.S. EPA TASK FORCE INDEMNIFICATION OBJECTIVES

At the request of the U.S. EPA Assistant Administrator for the Office of Solid Waste and Emergency Response, a Task Force was established to develop policy on indemnification of response action contractors working in the Superfund Program. The U.S. EPA Task Force research will form the basis for the development of the U.S. EPA RAC indemnification policy. The two major goals of the Task Force's research are: (1) to develop appropriate interim, U.S. EPA RAC indemnification terms and conditions and (2) to develop a RAC underwriting approach which will provide the P&C insurance industry with the technical assistance necessary to foster prospective commercial RAC liability insurance coverage.

The first major goal of the Task Force, to develop an interim Government RAC indemnification program, is vital to prevent the breakdown of the nation's Superfund hazardous waste site cleanup program because of the current lack of commercial liability insurance coverages for RACs active in Superfund site remedial work. The second major goal of the Task Force, to develop a RAC underwriting approach that the insurance industry can use to underwrite RAC liability insurance coverages, is vital to the creation of a commercial liability insurance market for RACs in the future. By providing the P&C insurance industry with this technical assistance. the U.S. EPA anticipates that the insurance industry in the future will replace Government indemnification of RACs. In doing its research, the Task Force anticipates considerable input from the P&C insurance industry. Furthermore, the Task Force intends that the P&C insurance industry will be the ultimate user of the U.S. EPA RAC underwriting approach that is developed and used by the U.S. EPA.

The U.S. EPA Task Force on the Indemnification of Response Action Contractors faces complex issues and difficult decisions in reaching its objectives. The Task Force objectives are:

- Determine the limits of U.S. EPA indemnification (above deductibles, commercial liability insurance and responsible party indemnification agreement layers) that are reasonable to offset probable and catastrophic risk RACs participating in the Superfund cleanup program.
- Identify the exposures/risks that RACs are subject to when participating in the Superfund cleanup program; identify the various legal sources of RACs potential liability losses, which result from a threatened release of any hazardous substance or pollutant or contaminant if such release arises out of response action activities, identify the potential liabilities for which RACs may be held legally liable when participating in the Superfund cleanup program.
- Determine the extent to which qualified/prudent RACs will avoid entering into Superfund cleanup contracts with the U.S. EPA if the limits of U.S. EPA indemnification, as determined by the Task Force, are set below what RACs deem to be an acceptable level of risk transfer; identify how the limits of U.S. EPA indemnification, as determined by the Task Force, affect the capacity and quality level of RACs available to perform Superfund cleanup activities; identify how the determined limits affect the U.S. EPAs ability to meet legislatively mandated EPA Superfund action schedules.
- Establish the underwriting criteria the the U.S. EPA will use to determine whether a RAC is an acceptable risk for U.S. EPA to indemnify; determine the terms and conditions of the indemnification contracts that the U.S. EPA will offer to RACs participating in the Superfund cleanup program.
- Determine the appropriate regulatory and/or administrative mechanisms necessary to implement and monitor the progress of the U.S. EPA's indemnification of RACS.

Figure 2 Potential RAC Liability Layers

The U.S. EPA indemnification of RACs will be governed by the terms and conditions determined by the U.S. EPA Task Force, as appropriate. The basis for selecting the appropriate terms and conditions is the assessment of RAC liability risks. The U.S. EPA Task Force will identify and estimate these risks. The baseline for determining what are adequate RAC indemnification terms and conditions is to establish the upper limits of indemnification that reasonably offset RAC probable risk (e.g., defense costs) and catastrophic risk (e.g., third-party liability suits). While maintaining incentives for adequate RAC performance (e.g., deductibles). Limits will be based on what is determined to be adequate to offset RACs liability risk associated with Superfund cleanups, thus assuring the continuance of the Superfund cleanup program.

The first step in establishing RAC indemnification limits will be to identify the scope of RACs Superfund cleanup activities (e.g., the types of work and disciplines involved) for RACs seeking indemnification. Potential loss exposures then will be identified from the scope of RAC Superfund cleanup activities.

The second step is to measure in dollar terms the potential liability risks that RACs face when participating in the Superfund cleanup program, related to the identified scope of work and disciplines involved. The estimated frequency and severity of RAC liability claims resulting from Superfund cleanups will be calculated by incorporating the following information: applicable historical loss data, technical and scientific data, spread of risk (e.g., potentially liable parties, role of the RAC, etc.), professional judgement and probability of risk.

The third step will be to create loss forecasts (based on the above information) that attempt to estimate the maximum possible loss and the maximum probable loss that RACs could face as a result of a given scope of Superfund cleanup activities. Once a range of potential liability losses is statistically estimated and/or established through professional judgement, the U.S. EPA and RACs.

In establishing RAC indemnification limits, the U.S. EPA will rely on input from the RAC community (e.g. risk managers, chief executive officers, etc.), professional insurance actuaries and underwriters, the legal community, the academic community and U.S. EPA contract specialists, technicians, scientists and legal counsel.

A survey of RAC liability risks will provide the initial information/data basis for this determination. Figure 3 delineates the components the U.S. EPA Task Force will incorporate into its policy analysis to determine the appropriate terms and conditions of the proposed RAC indemnification program. Once the assessment of RAC risks is made, the U.S. EPA Task Force will develop alternative indemnification limits and deductible levels in conjunction with professional actuaries. The Task Force will incorporate all the above information into the development of terms and conditions of the U.S. EPA RAC indemnification mechanism.

CONCLUSION

The U.S. EPA faces a challenge in developing and administering an indemnification program for the Superfund program's response action contractors, so that cleanup of the nation's hazardous waste sites will not be interrupted. Although such a program currently is justified for several public policy reasons, Congressional intent is to avoid establishing the Federal government's long-term presence as a surrogate insurance mechanism for the RAC community. Im-



Figure 3 Components for Determination of Proposed U.S. EPA RAC Indemnification Program Terms and Conditions

plementation of such a U.S. EPA indemnification program poses difficulties in the areas of constructing coverage limitations, determining deductible levels and other RAC indemnification terms and conditions.

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A Model for Apportioning The Cost of Closure of a Waste Site

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ABSTRACT

An approach has been developed for apportioning the costs of closure (and post-closure) of a hazardous waste site among the identified potentially responsible parties. The development of this methodology is principally in response to a need generated by the Federal Superfund Program for cleaning up hazardous sites as provided in CERCLA. The developed model utilizes predicted or actual costs of closure as the primary mechanism for apportionment. Consequently the developed system apportions the cost of eliminating or minimizing any potential threats to the environment from the wastes at a given site since that is the function of the closure plan. As currently developed, the model is not designed for use in apportioning the cost of any damages to human health or the environment.

The model is based on the contribution of a waste to the cost of closure rather than on other waste characteristics that have resulted in a hazardous classification. While such characteristics as carcinogenicity, oral or dermal toxicity, corrosivity, etc. are important in establishing the urgency of closure, these characteristics may have little bearing on the cost of the closure method to be implemented. The principal thrust of apportionment using this model is cost rather than characteristics. Total cost of closure is intended to include all costs associated with closure such as costs of the remedial investigation and feasibility studies and post-closure monitoring.

A model that can equitably apportion total cost of closure will be of value in prompt settlement of Superfund cases. Quick settlement will benefit all involved parties if expensive and lengthy litigation can be avoided. It is believed that the model described herein can be a step in the direction of expediting settlements.

INTRODUCTION

Cleaning up the nation's hazardous waste sites will require an immense effort. On June 1, 1986, approximately 800 sites had been named on the U.S. EPA's National Priority Listing which includes sites deemed to be eligible for cleanup funds under the Superfund program. The U.S. EPA estimates that the ultimate list will include 2,500 sites and that the cost of cleanup will amount to \$22.7 billion. The U.S. EPA's inventory of all hazardous waste sites that eventually will require closure currently lists approximately 19,000 sites.

The Office of Technology Assessment (OTA) has estimated that the number of priority sites will be much higher than estimated by the U.S. EPA and will ultimately increase to 10,000. Cleanup costs for these sites are estimated to amount to \$100 billion. The total cost of cleanup will be staggering regardless of who is correct.

Superfund legislation does not provide a method to apportion

the cost of closure in situations where more than one waste generator has been identified. As a result, apportioning these costs under Superfund has been left to the litigants and the courts. The usual plaintiff in a court action is the federal government and its position is that liability under Superfund is "joint and several." Under this concept, any single responsible party may be held liable for the entire amount of the costs of closure where liability is indivisible, or costs may be apportioned equally among a number of liable parties. This concept has appeal for the federal government because of its simplicity. The federal government can attempt to recover all closure costs from a select number of defendants. This simplifies the government's job. The task of bringing action against other responsible parties not named in the suit is left to the select number of defendants named in the federal government suit.

To date, courts have not established a clear cut policy regarding apportionment. Some courts have held that a defendant who wishes to avoid apportionment of costs by the "joint and several" concept has the responsibility to demonstrate that costs can be apportioned fairly by some other procedure. No such demonstration has been made to the satisfaction of a court.

However, it is obvious that apportionment of costs by the "joint and several" concept is not equitable. It consequently follows that an equitable apportionment method acceptable to the involved parties would be highly desirable.

There is a real temptation on the part of many potentially responsible parties to accept almost any method of apportionment to "get it over with." However, closure of some sites has shown that the actual cost of site closure can far exceed initial estimates. In addition, unexpected developments such as unanticipated contamination of adjacent areas can increase the cost of closure as much as an order of magnitude. An equitable apportionment will prevent the resulting cost burden from being borne by parties whose wastes may have contributed only slightly to unanticipated closure cost increases.

The magnitude of costs of closure and the lack of adequate cost apportionment methods have complicated litigation and discouraged out-of-court settlements. Such settlements are considered highly desirable by all parties for a multitude of reasons including litigation costs and the excessive time required in litigation.

CURRENTLY AVAILABLE MODELS

The U.S. EPA is considering a number of models to assist in settlement of Superfund closures. One model was developed to estimate the total cost of closure and all future expenditures involved in closure. Another was developed to estimate the cost of litigation. Yet another was developed to assess the ability of the potentially responsible parties to pay—a so-called "deep pocket" model. However, at this writing, a technically sound method of apportioning the cost of closure among the potentially responsible parties has not, to the authors' knowledge, been forthcoming.

Some models have been proposed which allocate costs principally on the basis of waste quantity and waste characteristics, such as toxicological properties, biological properties and other chemical and physical properties. While such properties may be pertinent to the potential of a waste to do harm to human health and/or to the environment and establishment of the urgency of closure, these properties are not relevant to actual costs incurred in closure in many cases.

THE PROPOSED APPROACH

An ideal method of apportioning costs would be one that realistically assesses the contribution of each company's waste to the cost required to eliminate or minimize the combined threats of all wastes present in the site to be closed. Since the closure plan, by definition, is designed to eliminate or minimize such threats, equitable apportionment of the cost of closure should accomplish this objective. The apportionment model described in this paper is called the DDA model. It is based on a realistic assessment of the impact of each waste on the total cost of cleanup of a particular site containing a particular mixture of wastes. The apportionment of costs among the involved parties using the DDA model is customized for a specific closure plan required for a specific site.

Closure of a waste site is a complex operation. Consequently, apportionment of costs of closure is not a simple matter. The rationale for the proposed apportionment method is described below.

Each waste present at a site to be closed may contribute differently to costs involved in each of the three phases of a closure plan:

- Surface Closure—elimination of potential threats to human health and the environment from waste constituents impounded or stored at the surface
- Shallow Subsurface Closure—elimination of such threats resulting from leakage into adjacent soil and the resultant soil contamination
- Groundwater Remediation—elimination of such threats from contamination of groundwater

The separate cost of each phase usually can be readily determined. Using unit costs for each phase, the cost contribution of each waste to each phase is then determined. The contribution of each waste to the overall total closure cost is the accumulation of the costs associated with each phase.

As shown later in this paper, this approach provides an apportionment that is customized for particular wastes at a particular site.

APPORTIONMENT EXAMPLE

The example presented in the following section shows the general method of calculation and also how site conditions alone may have a dramatic effect on both the total cost of closure and the apportionment of the closure costs. In the example, it is assumed that three companies each produce a specific and different waste. It is further assumed that identical quantities of each of these wastes have been deposited at three sites—each with significantly different soil and subsurface conditions.

Discussion of Apportionment Results

Table 1 shows that each company generated identical quantities of waste. Each waste was hazardous and heavier than water. Company A's waste has the lowest tendency to move through soils and is very low in solubility in water. Company C's waste has the greatest tendency to move through soils and is more soluble in water than the wastes generated by the other two companies. Company B's waste is intermediate in both mobility and water solubility between wastes generated by Companies A and C. Company C's waste has strong solvent properties and tends to form a solution of the other two wastes. As a result, Company C's waste tends to increase the rate of movement of the other two wastes through soils.

 Table 1

 Wastes Deposited—Quantities and Type at Example Site

Co.	Qty. of Waste (tons)	Type of Waste
Α	1000	Hazardous, high density, viscous aromatic oil containing benzo(a)pyrene, very low mobility in soil and very low solubility in water
В	1000	Hazardous, high density, less viscous aro- matic oil containing creosote, moderate mobility in soil and slightly soluble in water
С	1000	Hazardous, high density, low viscosity liquid waste containing chlorinated hydrocarbons, very mobile in soils and more soluble in water

 Table 2

 Site Soil and Subsurface Characteristics at Example Site

Site	Soil Permeability	Clay Depth (ft)	Depth to First Aquifer (ft)
1	Extremely low stiff clay	40	300 +
2	Moderate-silty clay	20	300+
3	High-sandy clay	0	30

Table 2 shows the variation in soil and subsurface characteristics at each of the three sites. The sites range from a stiff, low permeability clay with the first aquifer at a depth of 300 ft at Site

 Table 3

 Closure Plan Approach and Unit Costs at Example Site

Procedure	Units	\$/Unit
Surface Closure		
• Treat all free water in impoundment (use activated carbon) and discharge	K gal	50
• Excavate all wastes	tons	10
• Incinerate all wastes (off-site)	tons	400 (includes transportation)
• Backfill and vegetate	yd3	15
Shallow Subsurface Closure Excavate contaminated soil 	yd3	10
• Vault contaminated soil (as required) on-site	yd3	40
• Backfill	yd3	10
Groundwater Remediation • Recover contaminated groundwater; treat and discharge	K col	100
tical and discharge	r gai	100

1 to a sandy clay of high permeability and the first aquifer at a depth of 30 ft at Site 3.

Closure Plan

Table 3 presents the closure plan approach and unit costs for the steps required for closure of all three sites. The steps in each phase are summarized briefly below.

Surface Closure

- All contaminated free water in the impoundments will be treated and discharged under a temporary permit
- All impounded wastes will be excavated and transported for incineration off-site
- The emptied impoundment will be backfilled with clean soil. Topsoil will be added and the surface vegetated; handling of contaminated soil is discussed in the next section.

Shallow Subsurface Closure

- Contaminated soil will be excavated to an acceptable depth dependent on "how clean is clean" criteria
- Contaminated soil will be solidified as required and stored in an RCRA vault on the site
- Clean soil will be used for backfill

Groundwater Remediation

- Recovery wells will be installed as required
- Contaminated groundwater will be pumped from the aquifer as determined by "how clean is clean" criteria and treated using activated carbon prior to discharge under a state or federal permit

Apportionment of Costs

Closure costs can be expressed on an average unit cost basis for each of the steps in closure. These units costs then can be used in the determination of the contribution of each waste to the cost of closure for each step.

Tables 4, 5 and 6 present the information obtained from the assessment of each of the three sites in the example. It is also shown that contaminated free water is present in the impoundments at each of the three sites.

As shown in Table 4, there was no contamination of soil or groundwater at Site 1 resulting from any waste since the soil is a very stiff, low permeability clay.

Table 5 indicates that at Site 2 there was soil contamination from wastes from Companies B and C but none from Company A's waste. The soil at Site 2 was of relatively moderate permeability.

However, Table 6 shows that both soil contamination and groundwater contamination occurred at Site 3 since soil was relatively permeable and the first usable aquifer was quite shallow.

 Table 4

 Site 1 — Information from Site Assessment

Co.	Wasie Type	Qty. of Waste (tons)	Qty. of Contaminated Soll (yd3)	Qty. of Contaminated Groundwater (K gal)
Α	WA	1,000	0	0
В	WB	1,000	0	0
С	WC	1,000	0	0

Quantity of Contaminated Free Water in Impoundment - 100 K gal

Table 5 Site 2 — Information from Site Assessment

<u> </u>	Wasie Type	Qty. of Waste (lons)	Qty. of Contaminated Soil (yd ³)	Qty. of Contaminated Groundwater (K gal)
A	WA	1,000	0	0
В	wB	980	1,000	0
С	Wc	800	8,000	0

Quantity of Contaminated Free Water in Impoundment - 100 K gal

Table 6 Site 3 — Information from Site Assessment

Со	W as te Type	Qiy. of Waste (tons)	Qty. of Contaminated Soli (yd3)	Qty. of Contaminated Groundwater (K gal)
	W.	980	1.000	100
B	W _B	900	2,000	1,000
С	₩c	700	10,000	10,000

Quantity of Contaminated Free Water in Impoundment - 100 K gal



NO CONTAMINATED BOIL OR GROUND WATER



NO CONTAMINATED GROUND WATER



Figure 1 Results of Remedial Investigation

Fig. 1 presents a schematic indicating qualitatively surface water, soil and groundwater contamination at each of the three sites.

Tables 7, 8 and 9 present the calculations of the share of closure costs for each company at each site. The total cost of closure and

the pro rata share of each company as calculated using the proposed method is summarized below:

Company	Site 1 Share			Site 2 Share	Si St	te 3 Iare
	K\$	970	K\$	⁰⁷ 0	K\$	9%0
Α	427	33.33	426	24.6	487	15.70
В	427	33.33	478	27.60	615	19.90
С	427	33.33	826	48.80	1,995	64.40
Totals	1,281	100.00	1,730	100.00	3,097	100.00

NOTE: Costs associated with the RI/FS, post-closure monitoring and all other similar costs were not included in this example. Such costs should be included in total closure costs and should be apportioned on the same basis as calculated for closure costs shown above.

Table 7Site 1 — Proration of Closure Costs

			Cast.	Pertian	of Cost to la Company, Ki	wicated 5	Overall Closure
	Quantity	Units	\$/Unit	A	В	C	Total, K\$
SURFACE CLOSURE o Treat Contaminated Surface Water							
A	33	Kgal	50	2	-	•	2
в	33	Kgal	50	-	2	-	2
с		Kgal	50	<u> </u>	<u></u>	_1	
Subtotals	001			2	2	2	4
o Excavate Vastes		а					
Ê	1,000	24	10	10	10	-	10
6	1,000	3	10	-	10	10	10
Subtotals	3,000	,-		10	10	10	30
o Inconstate Maste							
A	1,000	т	400	400	-	-	400
в	1,000	т	400	-	400	-	400
с	1,000	т	400	<u> </u>	<u> </u>	<u>+00</u>	000
Subtotals	3,000			400	400	400	1,200
o Backfill and Vegetate							
A -	1,000	yd]	13	15	•	-	15
в	1,000	703	L L	-	15	.:	15
C	1,000	ya-	15	<u> </u>		12	
Subtotals	3,000			19	15	19	45
SHALLOW SUBSURFACE N/A	CLOSURE						
GROUND WATER REME	DIATION			<u> </u>	_ - _	<u> </u>	
	Totals			427	\$27	427	1.281
	% Share			33.3	33.1	11.1	100
				2212			

 Table 8

 Site 2 — Proration of Closure Costs

			Cort.	Pertion of Cost to Indicated Company, K\$			Overall Closure
	Quantity	Unita	5/Unit	<u> </u>	<u>_B</u>	<u>_</u>	Total, K\$
o Treat Contaminated Water	100	K gai	50	2	2	2	6
o Excavate Waste	2,780	yd ³	10	10	10	10	30
o Incinerate Waste							
٨	1,000	т	400	400	•	-	400
8	980	т	400	•	392	•	392
с	_ 100	т	000	<u> </u>	<u> </u>	320	320
Subtotals	2,780			400	392	320	1,112
 Backfill and Vegetate 	2,780	yd ³	19	14	14	14	42
SHALLOW SUBSTIREACT CL	051187						
Excevete Conteminated Second	ui fand backfil	D .					
A	0	" vd3	20	-	-	-	-
В	1.000	vd ³	20	-	20	•	20
С	8,000	yd3	20	<u> </u>	<u> </u>	160	160
Subtotals	9,000			•	20	160	190
• Vault Contaminated Soll							
٨	0	yd3	40	-	-		0
B	1,000	yd3	40	-	40		40
c	8,000	yd 3	40	<u> </u>	<u> </u>	320	
Subtotals	9,000				40	320	360
GROUND WATER REMEDIA	NON						
N/A						<u> </u>	<u> </u>
	Totals			426	478	826	1,730
	% Share			24.6	27.6	\$7.8	100

 Table 9

 Site 3 — Proration of Closure Costs

			Cast	Portion	of Cost to I	ndicated	Overall
	Quantity	Units	S/Unit	<u> </u>	_ <u>B</u>	<u> </u>	Total, KS
SURFACE CLOSURE o Treat Contaminated Water	100	K gal	50	2	2	2	6
o Excavate Wastes	2, 580	yd ³	10	10	10	10	30
o Incinerate Waste	2, 580	т	400	392	360	280	1,032
o Backfill and Vegetate	2, 580	yd ³	15	13	13	13	39
SHALLOW SUBSURFACE CLOS	JRE						
 Excavate Contaminated Soll. and backfill 	13,000	yd 3	20	20	40	200	260
o Vault Contaminated Soli	13,000	yd ³	40	40	80	400	520
GROUND WATER REMEDIATIO	N						
٨	100	Kgal	100	10	-		10
в	1,000	Kgal	100	•	100		100
C	10,000	K gai	100	<u> </u>		1,000	1,000
Subtotals	11,000			10	100	1,000	1,110
Totals				487	61 5	1,995	3,097
* 5	hare			15.7	19.9	64.4	100

As indicated, variations in only site conditions resulted in an increase in closure costs from 1,281K at Site 1 to 3,097K at Site 3. Company shares ranged from a 33.33% for each company at Site 1 to 15.7% for Company A, 19.9% for Company B and 64.4% for Company C at Site 3.

The simplified case shows only three companies and three wastes involved at the disposal sites. However, when many companies are involved and each produces several wastes, this approach involves numerous calculations. The model handles the arithmetic manipulations required.

APPROACH WHEN MANY PARTIES ARE INVOLVED

How can the DDA model approach be used in apportioning closure costs when a large number of parties (each of which may have produced several wastes) is involved in a site? Since involvement of that many companies is not unusual, the answer to this question is of great significance. At many sites, 50 or more parties may be involved. In most cases, when a large number of parties deposited wastes at an inactive site, one or both of two conditions may exist. Many of the parties may have deposited only small amounts of waste and/or some of the parties may not have been identified. For parties known to have deposited a small quantity of wastes of moderate toxicity, say 1% or less, at the site in question, it is recommended that the actual percentage of the waste deposited be used as a basis for apportionment of the total cost of closure. (However, this approach should be reconsidered if the small quantities of waste are particularly mobile in soils and found to contribute to contamination of soils and groundwater far in excess of the percentage of the overall quantity of wastes at the site.) The model can then be used to apportion the remaining cost of closure among those parties whose shares exceed 1%. The pro rata shares determined on this basis would apply to the entire cost of closure including costs associated with wastes from parties not identified.

There may be cases in which the presence of one waste (or a small number of wastes) may dictate the disposal technique that will be required for all of the wastes present in a site. For example, if even a small amount of PCBs was deposited by one party and mixed with other wastes at a site, the presence of this particularly hazardous waste probably would result in the mixture of wastes at the site coming under the U.S. EPA requirements for handling PCBs and/or PCB-contaminated waste. Conventional landfilling (vaulting) may have been an acceptable disposal technique for all other wastes at the site, but contamiantion by PCBs may have resulted in all of the wastes being classified as PCB-contaminated with the result that these wastes may require incineration in a facility permitted for such wastes. Some of the wastes with lower PCB contamination may require vaulting in one of the few land-fills permitted by the U.S. EPA to handle such wastes. The presence of only a small amount of PCBs should thus result in a dramatic increase in the cost of closure of the site. The question of how to apportion closure costs in such a case becomes very important. Such questions would arise as:

Should the party who deposited the PCB waste bear the entire increased cost of closure that results from the presence of PCBs?
What part of the increased cost should the other parties bear?

One school of thought would suggest that the party that deposited the PCBs was in the best position to know what problems were being caused and consequently that party should bear the entire added cost of closure resulting from the presence of PCBs.

Another school of thought may suggest that all parties should share "equally" based on the apportionment method used in the total cost of closure on the basis that those parties whose waste did not contain PCBs should have been aware of the risk that they were incurring by depositing waste at the site in question. This attitude employs the so-called "cesspool" effect—or guilt by association.

Perhaps, a better solution than either of these positions would be an intermediate course. This approach would involve estimates of the cost of closure if each waste had been deposited separately. The sum of these costs could be determined as the cost of separate closure. This sum could be deducted from the actual cost of closure which would include the effect of the presence of PCBs. The difference would represent the added cost resulting from the presence of PCBs. This added cost could be split in half, with one half being borne by the party who deposited the PCB waste and the other one half apportioned among the remaining parties on the same basis as used in the DDA model approach. This approach would penalize the generator of the hazardous waste that controls the method of closure more than the other parties who deposited waste at the site.

INFORMATION REQUESTED FOR APPORTIONMENT

To employ the DDA model approach, one should use as much of the following type of information as is available:

- The quantity and properties of each of the wastes that each company had delivered to the site
- The closure plan expressed in such a way that unit costs can be expressed for:
 - -surface closure
 - -any required shallow subsurface closure
 - -any required groundwater remediation

This type of information is continually being improved from initial preliminary evaluation through final closure and consequently would be available at a number of stages of development of closure. Some of the stages at which estimates would be available are:

- Completion of preliminary site assessment
- Completion of Remedial Investigation and Feasibility Study (R1/FS)

- Final design for closure
- Completion of closure

Since apportionment of costs is essentially driven by the cost of closure, estimates of apportionment can be made at any point in the development of closure at which cost estimate is available. Generally, a preliminary apportionment made at an early stage in closure development is suggested to provide guidance for the potential responsible parties regarding their approximate shares of the cost. However, the most accurate apportionment is based on the final actual cost since the best information is available at that point. The proposed procedure is dynamic and can provide the most realistic apportionment upon actual closure even if some unanticipated development arises during closure.

A number of suggestions regarding site closure and handling of the model are presented in Table 10.

Table 10 Suggestions for Handling Site Closure And Proration of Closure Costs

- · Form a Steering Group to administer closure
- Set up a fund to cover initial costs including the Work Plan, RI/FS and design of closure
- Obtain agreement on a method for prorating closure (and postclosure) costs
- Develop first pass proration based on initially available data
- · Use the agreed upon procedure to prorate the costs of closure

Note: The names of the companies should not be divulged to the modeler when supplying waste quantities and properties. A coding system should be used to reduce subjectivity.

The formation of a Steering Committee composed of representatives of the potentially responsible parties is a generally accepted first step. It would be desirable for this group to provide a fund for the expenses to be incurred in development of the Work Plan, the RI/FS and closure and post-closure design. These costs would later be included in the final apportionment of costs. It would be desirable to obtain agreement on a method of apportioning closure costs at an early point. A first pass apportionment should be developed on the basis of data available at an early stage for review by the potentially responsible parties. Agreement should be reached on the stage in closure development at which final apportionment will be based. Objectivity can be enhanced by using code names when supplying information about the wastes that were generated by the various companies to the modelers.

CONCLUSIONS

Apportionment of the costs of closure and post-closure is a major problem with for federal and state agencies and the potentially responsible parties. One of the primary objectives of all involved parties is expeditious settlement to avoid delays and costs associated with prolonged litigation. It is believed that the method described herein will provide an equitable basis for apportionment and thus expedite closure settlements.

Considerations of Discounting Techniques Applied To Superfund Site Remediation

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ABSTRACT

Selection of a remedial action alternative for Superfund sites involves consideration of several factors including technical and socioeconomic factors that are often difficult to compare. The remedial action decision-maker is forced to compare the economic costs for varying technologies and differing cash flow requirements. To facilitate the cost comparison, a discounting technique—the net present worth concept—is used to produce a single cost value.

While the net present worth concept simplifies the economic comparison of alternatives, it fails to fully reflect the costs associated with each alternative. Its shortcomings include failure to fully differentiate the impacts of inflation and project risk. The use of a sensitivity analysis helps reduce the economic uncertainty in selecting an alternative. However, the decision-maker must be aware of the limitations of the net present worth technique if sound economic decisions are to be made.

This paper explores the application of the net present worth technique to Superfund site remediation decisions. The assumptions necessary for use of the technique are examined as are its shortcomings in addressing inflation and differing levels of project risk. The sensitivity analysis also is discussed and explained by use of an example.

INTRODUCTION

The selection of a remedial alternative on sites being managed under CERCLA is based on several decision criteria including engineering reliability, implementability and constructability; environmental and public health impacts; institutional issues; and project cost. These factors collectively serve as input to the process of selecting a recommended or preferred alternative for remediation of a particular site. The total number of sites that can be remediated is directly related to the number of sites entering the Superfund system, as well as to the balance in the trust fund established by Superfund to finance cleanups. Clearly, the alternatives that meet the U.S. EPA policy objectives and result in the least financial expenditure are preferred.

While technologies that treat or destroy hazardous wastes and substances are developing due to market demand pressures, the cost of implementing these technologies is often difficult to estimate. Part of this difficulty stems from uncertainty with respect to economies of scale, competitor behavior, regulatory compliance and operating efficiencies realized through full-scale applications. Additional uncertainty can be caused by lengthy implementation times between selection of a remedy and the actual application of the technology. The decision-maker faces the additional challenge in comparing alternatives offering different waste management strategies such as land disposal and waste incineration. It is difficult to choose between land disposal options and a more expensive destruction option such as incineration, when concerns over future releases and resultant liabilities are factored into the decision process.

Discounting is the conventional method of comparing economic costs of alternatives with differing cash flow requirements. This method allows the decision-maker to evaluate all alternatives in terms of a single, base year cost. Discounting techniques are quite effective in such applications, but use and interpretation discounting models can be misleading, particularly if the decision-maker is not aware of the method's limitations.

DISCOUNTING TECHNIQUES

Capital budgeting decisions are based on a number of techniques with the payback method, the net present worth method and the internal rate of return, employ the discounting concept.

The discounting concept is based on the realization of the value of a dollar with respect to time. Simply stated, the premise is that the value of \$1 to be received or expended at some time in the future is worth less than the value of \$1 today. The difference in value depends on the interest rate and the length of time the amount of money could be invested to yield or provide \$1 in the future. For example, \$1 spent 1 yr from now is worth less than \$1 today because it is discounted by the amount of interest it would earn in the intervening year. In this sense, the interest rate is referred to as the discount rate, usually stated as a per annum percentage.

The term "present worth" is an amount at some beginning or base time that is equivalent to a particular schedule of receipts or disbursements under consideration. If only disbursements or expenditures are considered, the term can be expressed best as "present worth cost." By discounting all future costs to a common year base, the costs of various alternatives can be compared on the basis of a single figure. This figure represents the resources in today's dollars needed to meet the future expenditures associated with a particular alternative.

The net present worth technique uses the discounting concept. Cash receipts in future years are discounted to a base year. Similarly, the costs to build, operate and maintain a proposed project are calculated and discounted to the same base year. The net present worth is calculated as follows:

Businesses prefer alternatives with the highest net present worth as they maximize the value of the firm. If an alternative involves only expenditures, the net present worth will be negative. In this case, the least negative alternative represents the preferred alternative.

Net present worth can be expressed as the equation (2):

NPW =
$$\sum_{i=1}^{n} \frac{Ft}{(1+k)^n} - 1$$
 (2)

where:

- NPW = net present worth
- F = net cash flow in year t
- k = discount rate
- I = initial investment
- n = number of years from time t = 0.

As indicated by the above equation, the information needed to calculate the net present worth includes the cash expenditures and receipts for each year of the life of the alternative, the assumed discount rate, the initial investment required and the expected number of years in the life of each alternative.

The internal rate of return method involves calculation of the interest or discount rate required to make the net present worth of an alternative equal to zero. Instead of comparing net present worth values, this method compares the interest rates of return. Decisions which maximize the value of the firm require selection of the highest rate of return. While this method is widely used by industry in making a selection among several alternatives competing for limited available investment funds, it is not appropriate to Superfund site decisions because of the difficulty associated with quantifying the economic benefits of site remediation. This method is also tedious; it requires trial and error solutions to determine the one interest rate which makes the net present worth equal to zero.

CURRENT APPLICATION TO SUPERFUND SITES

U.S. EPA guidance documents^{3, 4} specify the use of present worth analysis to compare remedial alternatives. The develop-



Figure 1 Feasibility Study Cost Evaluation Process

ment of cost estimates for remedial action alternatives involves the following steps:

- Estimate of Costs—estimate the capital and annual operating costs
- Economic Analysis—using estimated costs, calculate annual and present worth costs for each remedial action alternative
- Sensitivity Analysis—evaluate the cost-effectiveness of selected modifications of present worth estimates for those variables which, by inspection, have a significant cost sensitivity

The procedure is shown in Fig. 1.

Assumptions to be made in performing the present worth analysis are:

- No inflation of costs—in accordance with the Office of Management and Budget (OMB) Circular A94, costs in future years should not be adjusted 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 alternatives
- Discount rate—use a before taxes and after inflation rate of 10%, which represents the average rate of return on private investment
- Period of performance—should not exceed 30 yr

The U.S. EPA alerts users to the impacts that differing discount rates can have on alternatives with high annual operating and maintenance costs and relatively low initial costs. Such impacts are to be evaluated in the sensitivity analysis, defined as a procedure for analyzing the change in the net present worth resulting from a change in one key variable, "ceteris parabus" (all other factors held constant). In addition to the discount rate, such key variables typically evaluated in a sensitivity analysis include the following:

- Waste quantities
- Treatment process unit costs
- Distances to off-site facilities to receive wastes
- Implementation times to achieve remedial objectives

The range of variation for each key parameter is left to the discretion of the evaluator, although the variation of the discount rate is suggested to be 10%, 4% and 7%. The sensitivity analysis is intended to identify the parameters which could change the relative ranking of an alternative with respect to cost. It also makes the decision-maker aware of situations where changes in external parameters, due to continued development of a technology or higher than projected operating costs, for example, could change the preferred alternative for a given site. The sensitivity analysis helps define the uncertainty inherent in the preparation of cost estimates.

CRITIQUE OF PRESENT WORTH METHOD

The application of the net present worth method of analysis to Superfund site remediation alternatives, as well as to more conventional business investment problems, has the advantages of being relatively easy to calculate and reducing a complex cash flow series to a single value. There is a danger, however, of misinterpreting the results if the decision-maker is not fully aware of the assumptions used and the limitations inherent in the analysis.³ Two such limitations are (1) failure to consider inflationary impacts and (2) failure to adjust the discount rate to reflect differing risk premiums among the array of alternatives.

Inflationary Impacts

The OMB A94 circular states that inflation is not to be factored in the projection of cash flows unless there is a reasonable basis for predicting the differences in the relative escalation of costs associated with the project. Inflation usually is measured by the Consumer Price Index (CPI), although other, more discriminating indices are available. The CPI is a composite index that includes the costs for housing, food, energy, health services, etc. Subgroups of the CPI, particularly energy prices, are likely to have a greater impact on cash flow projections associated with remedial actions than the cost of housing. Recent history provides strong evidence that projecting the inflation or deflation of energy prices contains a large factor of uncertainty. Therefore, it is likely that energy-intensive alternatives, such as "pump and treat" or incineration, can significantly underestimate or overestimate the costs in future years.

The error that arises from failure to include inflation in cash flow estimates is compounded with time as long as inflation is positive. This results in understated distant cash flows tending to favor alternatives which involve long-term treatment or active migration prevention systems and long-term storage.

Inflationary expectations of investors are an intrinsic component of the discount rate, for investors will invest funds at differing interest rates and for differing periods of time based in part on their guess about inflation. The discount rate, therefore, includes an allowance for inflation. The inflation expectation rates for businesses and for the government will be different, as they operate in different economic arenas. Use of the 10% discount factor appears more appropriate to the business sector than for the U.S. EPA, which understates the present worth of distant year expenditures for government financed projects.

Risk Premiums

In practical terms, the discount rate consists of three components: a risk free value of money, an inflationary expectation adjustment and a risk premium. The last component is a function of the amount of risk associated with a given alternative. The current practice of utilizing a constant discount rate implies all alternatives are subject to the same degree of risk. Yet, it is arguable whether the alternatives that involve destruction of hazardous substances are preferable to alternatives that are based on storing wastes for an indefinite period, because the destruction alternative eliminates the long-term threat of future release of the substance into the environment.

Thus, the long-term risk to the public health and the environment associated with destruction technologies is usually considered lower than for storage alternatives. Similarly, the risk associated with innovative and developing technologies not proven in the field is considered higher than the risk associated with proven technologies.

The discount rate can be calculated as follows:5

$$(1+K) = (1+Rf) (1+Ei) (1+Rp)$$
 (3)

where:

K = discount rate

Rf = risk free value of money

Ei = premium for inflationary expectations

Rp = risk premium

Holding the risk premium component of the discount rate constant for all alternatives fails to acknowledge the differing risk levels associated with the technologies. While establishing a risk premium for each management alternative could be cumbersome and subject to rapid change, a small number of risk classes could be set up, with a different risk premium being assigned to each class.⁶ This would give the remedial site project manager a clearer economic indicator on the alternatives being evaluated.

EXAMPLE OF NET PRESENT WORTH ANALYSIS

To further explore the net present worth method, consider the following example. One decision to be made on a Superfund site addresses remediation of the threat to public health posed by contaminated groundwater. Two technologies have been declared feasible in the pre-screening process. One technology consists of containment of the contamination by means of a slurry wall system. The second technology involves removing the contaminated groundwater, treatment at an on-site water treatment facility and re-injection of the effluent back into the contaminated aquifer.

The risk associated with this latter alternative is considered higher because it is uncertain whether sufficient quantities of contaminants can be removed to lower the public health threat to a level where no further remedial action is required. Modeling of the contaminated aquifer indicates that pumping and treating will be required for at least 50 yr to achieve a concentration approaching the one additional cancer in 100,000 (10^{-5}) risk level.

The alternatives and their costs are given in Tables 1 and 2. These tables present the installation costs in 1986 dollars for each alternative as well as the annual operation and maintenance costs. The net present worth calculations are shown using a discount rate of 10% and no allowance for inflation.

As shown in the tables, the net present worth cost of the "pump and treat" alternative is \$4.02 million, and the net present worth cost of the slurry wall is \$8.07 million, more than twice the cost of the pump and treat alternative. How would the costs differ if a lower discount rate were used and inflation were factored into the equation?

To answer this question, a sensitivity analysis was performed. The discount rate was changed from 10% to 4%, and a 2% inflation adjustment was factored into the projected costs. Table 3 summarizes the results of the analysis. The sensitivity of the discount rate is shown by comparing the net present worth values at 10% and 4%. The pump and treat alternative is not as economically attractive at the lower discount rate because of the larger annual expenditures for operation and maintenance.

Because of these higher costs, the impact of inflation was thought to be critical. Therefore, the annual expenditures were

Table 1 Containment by Slurry Wall

Description of Technology:

Construct slurry wall around contaminated aquifer. To control hydraulic gradients, install media (gravel) drains around top of wall and remove small quantity of water. Treat water and discharge. Install cap over site to reduce inflation.

Annual operation and Maintenance:

Maintain and replace cap as needed. Maintain drains and treat groundwater removed.

Installation Cost:

\$7,510,100 (1986 dollars)

Annu	al	C	os	ts:	
-		-			

Cap Maintenance	\$ 8,000
Drain Maintenance	2,500
Treatment Costs	23,900
Site Monitoring	25,000
	\$59,400

Net Present Worth:

(30 yr, 10% discount rate)

NPW = (- annual costs) (present worth factor) – Installation Costs NPW = (-59400) (9.427) – 7,710,000 NPW = -\$8,070,064 inflated by 2%/yr for both alternatives, and the net present worth values were calculated. As demonstrated by the 2% inflation and 4% discount rate scenario, the pump and treat alternative is approaching the cost for the slurry wall alternative, reflecting the impact of inflation on the operation and maintenance costs. Larger inflation rates would drive the cost of the pump and treat alternative at a higher rate than the slurry wall alternative. Clearly, the cost comparisons are quite sensitive to inflation.

Table 2 Pump and Treat

Description of Technology:

Install extraction wells, pumps and header system. Remove contaminated water and treat in on-site treatment facility. Inject effluent into aquifer to facilitate removal of contaminants.

Annual Operation and Maintenance:

Maintain and replace wells, pumps and header system. Purchase chemicals for water treatment and maintain treatment facility. Electricity for well pumps, labor, to operate equipment.

Installation Cost:

\$1,485,550

Annual Costs: Extraction \$111,600 Injection 127,200 Treatment 103,300 Monitoring 49,000

\$391,100

Net Present Worth:

(30 yr, 10% discount rate) NPW = (-annual costs) (present worth factor) - installation cost NPW = (-391100) (9.427) - 1485550 NPW = -\$4,021,413

Tabi	e 3
Sensitivity	Analysis

Net Present Worth (1986 dollars)						
	0% inflation 2% inflation					
	10%	4 %	10%	4 %		
Slurry Wall	- 8.07	- 8.54	- 8.19	- 8.85		
Pump and Treat	- 4.02	- 5.98	4.46	- 7.34		

CONCLUSION

The net present worth discounting technique is valuable in facilitating the cost comparisons of remedial actions by virtue of its ability to combine future expenditures with installation costs. It is relatively simple to use and calculate. Yet such simplification of calculations can lead to faulty decisions if the limitations of the technique are ignored.

The limitations include failure to fully consider the impacts of inflation and different project risk levels. Alternatives that include large annual operating and maintenance costs are affected by inflation to a much higher degree than capital-intensive alternatives. Alternatives associated with long-term cash flows (e.g., 20 to 30 yr) and times of positive inflation are undervalued.

The project risk for each alternative is difficult to quantify and is assumed equal in present applications. Alternatives that destroy hazardous substances contain a lesser risk for additional releases than landfill or capping alternatives. Recent feasibility studies indicate that the costs of landfilling or capping alternatives are significantly lower than destruction alternatives such as incineration. Theoretically, this difference in cost can be accounted for by assigning different risk premiums to different technologies. This change would further facilitate the economic comparisons on Superfund sites.

Developing the risk premiums for each technology would require input from waste management experts, engineers, scientists and perhaps even those members of the public most affected by the remediation effort. Such value judgments are not conducive to quick consensus, but nevertheless could serve the Superfund remediation process by facilitating decision-making and generating more meaningful discussion of the relative merits of each alternative.

The French philosopher Paul Valery said that a fact poorly observed is more treacherous than faulty reasoning. By being aware of the net present worth limitations and assumptions, the remedial decision-maker can make better decisions.

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The Application of Quantitative Risk Assessment To Assist in Evaluating Remedial Action Alternatives

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ABSTRACT

The application of a quantitative risk assessment is employed to evaluate the cost-effectiveness of remedial action alternatives. A four-stage cancer model was employed to evaluate the risk of ingesting groundwater contaminated with four carcinogenic chemicals to the exposed population. Three remedial actions were evaluated (including no-action) to assess the level of risk reduction following implementation. Baseline risk was evaluated as the equivalent of 14 excess cancers over the 30-year exposure period studied during the analysis.

Under the implementation of the remedial alternatives, the baseline risk was reduced by 58% using a groundwater treatment system and 72% using a containment wall and groundwater treatment system. The net present value costs for each system are calculated, and the marginal costs for implementation are compared with the incremental reduction in cancer risk. The results suggest that the marginal costs for implementing the more costly alternative should be examined carefully in terms of expenditures per number of incidents avoided.

INTRODUCTION

The application of quantitative risk assessment has become an increasingly important component in the evaluation of remedial alternatives at abandoned hazardous waste disposal sites. This type of analysis is employed initially to identify the baseline level of risk associated with both current site conditions and the no-action alternative. A subsequent analysis then is completed to evaluate the reduction in the baseline risk that is anticipated following the implementation of remedial alternatives. This reduction in public health risk which might be measured, for example, in terms of reduction in the expected number of cancer incidents, then can be employed to assess the effectiveness of the proposed remedial alternatives and examine the costs incurred to reduce risk to targeted lower levels.

A previous study² presented an approach to employ quantitative risk assessment to evaluate remedial alternatives. This approach was based upon extrapolations from work completed by the U.S. EPA Carcinogen Assessment Group (CAG) and served as a basis to develop a risk assessment methodology. This current analysis is an extension of the initial study and incorporates several additional concepts into the analysis procedure.

The first modification of the U.S. EPA work relates to the evaluation of age-specific considerations with respect to the incidence of risk in a known population. The second modification incorporated into the analysis is the evaluation of dose attenuation following the implementation of a remedial action program. The incorporation of these two factors into the analysis provides the ability to more realistically evaluate potential public health impacts upon a specific population (of known demographics) exposed to contaminants migrating from hazardous waste disposal sites.

APPROACH

The risk assessment approach used in this analysis was reported previously and is summarized in Fig. 1. The critical elements in the risk assessment include the identification of those hazardous substances which have migrated from the site (target contaminants) and impacted (via ingestion of groundwater) upon a known receptor population (population at risk). Also, it is important to establish the dose-response relationship for human ex-



Figure 1 Risk Assessment Methodology

posure to the target contaminants and to evaluate dose reduction in response to the implementation of a specific remedial alternative.

Target Contaminants

This analysis examines the risk to an exposed population associated with the ingestion of drinking water containing lowdose levels of four hazardous substances which have been evaluated for carcinogenic potency by the U.S. EPA CAG. The CAG evaluation of carcinogenic potency is based upon application of a linear multi-stage model (others are available) to evaluate cancer risk associated with a continuous lifetime exposure (70 years) to a carcinogen via ingestion of 2 l of water per day contaminated with the carcinogenic substances. A typical dose response curve is shown in Fig. 2; a linearized curve (dashed line) which is considerably more conservative in the low dose region being evaluated in this analysis also is shown for comparison.



The four chemicals identified in drinking water included benzene, trichloroethylene, chloroform and 1,2-dichloroethane. Benzene and trichloroethylene were measured at 20 μ g/l, respectively, and chloroform and 1,2-dichloroethylene were measured at 10 μ g/l.

Population at Risk

The population at risk is represented by a hypothetical agespecific grouping having characteristics which are based upon the 1980 U.S. Census. The exposed population consists of nine individual groups which are stratified on the basis of age. The predominant grouping in terms of numbers is the 15-24 age group with 18.6% of the total populations of 100,000.

The population does have a dynamic quality; the birth rate is assumed to be 20 per 1,000, the death rate is calculated at 850 per 100,000 and no migration from the study population is allowed.

Remedial Alternatives

There are three remedial action alternatives considered for this particular program, including the option for no-action. The technology-based remedial alternatives employ the concepts of either treating the contaminated groundwater or both containing and treating the groundwater.

The groundwater treatment option includes the provision for locating two clusters of extraction wells on-site and off-site. The extracted groundwater is treated to remove volatile organics and metals prior to discharge to a POTW. The on-site wells will be operational for 30 years while the off-site wells will be sequentially phased out of service after 10, 20 and 30 years. The groundwater containment and treatment option not only relies upon groundwater extraction and treatment, but also employs a containment wall to control the migration of contamination from the source. This system will operate for 30 years but will reduce the time required to achieve a steady state of groundwater contamination such that the dose of contaminant received by the exposed population is less than that associated with the groundwater treatment option.

It is assumed that the relationship between the relative levels of groundwater contamination and the time following implementation of the individual remedial alternatives is represented by a series of step functions. Each technology-based remedial alternative will achieve a similar level of residual groundwater contamination following 30 years of operation. However, this level of control is achieved in a shorter time-frame when the containment wall is employed in combination with a groundwater extraction and treatment system.

Risk Model

The analysis for cancer risk associated with the ingestion of contaminated drinking water utilizes the application of a multistage model. This type of model is based upon the assumption that the degeneration of a cell to the malignant state is represented by a series of sequential processes or stages. The individual number of stages is variable but usually ranges from three to six. Transfer from one stage to another can be in response to dose dependent initiating or activating events, while transfers from other stages may occur as random events.

This following analysis of cancer risk is based upon the recent efforts of Crump and Howe,' who present an approach which enables the analyst to incorporate consideration of factors such as short-term exposures, time-dependent dosage patterns, age at the onset of exposure and the relationship between dose and the various stages of the cancer process into the assessment of cancer risk.

This analysis evaluates the cumulative lifetime cancer risk to a person exposed to a constant dose of a carcinogen beginning at age S_1 and continuing for a duration of $(S_2 - S_1)$. The lifetime risk must also reflect consideration for the number of stages which comprise the multi-stage process and the individual stage(s) which is/are identified as being dose dependent. The number of individual stages which represent the cell transformation process is identified as K; the dose dependent stage is identified as r.

Given that the initial stage in the carcinogenic process is dose related (as might be the case with an initiator as opposed to a promoter), then the risk H(t) is given as:

$$\begin{array}{ccc} 0 & t < S_{1} \\ H(t) = (d)(c) & (t - S_{1})^{k} & S_{1} \leq t S_{2} \\ & (t - S_{1})^{k} - (t - S_{2})^{k} & S_{2} \leq t \end{array}$$

where:

H(t) equals the cumulative cancer incidence due to exposure t is the individual's present age

- d is the dose level
- c is a constant term based upon carcinogenic potency
- k represents the number of stages prescribed by the carcinogenic process
- S₁ is the age of the exposed population at the onset of exposure
- S₂ is the age upon termination of exposure
- c is a constant which represents carcinogenic potency

The cumulative incidence of cancer associated with a shortterm environmental exposure can be related to the CAG estimate (lifetime exposure evaluation) at the same dose level to evaluate the fraction of lifetime cancer risk which manifests itself during the short-term episode. This expected level of risk (F) measured as a fraction of the lifetime risk estimate can be calculated using Equation 2:

$$F = \frac{\frac{t=S_1}{t=S_1} + \frac{(t-S_1)^k}{70} + \frac{70}{t=S_2} + \frac{(t-S_2)^k}{(t-S_1)^k} + \frac{(t-S_2)^k}{(t-S_2)^k} + \frac{(t-S_2)^$$

Equation 2 was utilized to generate a family of curves shown in Fig. 3 which describe the relative risk to individuals exposed to an environmental carcinogen; the curve shows the risk variation as a function of both age at onset of exposure and the duration of the exposure episode. The carcinogenic process was assumed to be a four-stage process with the first stage being dose dependent and subsequent transformations represented by the random events. This family of age-specific curves establishes the relationship between the years of exposure to an environmental carcinogen (<70) and the percentage of the lifetime risk (as per CAG) which is associated with this limited duration exposure. These curves



Figure 3 Cancer Risks vs. Years of Exposure by Age at Exposure Onset

provide a mechanism to calculate the age-specific exposure risk estimate utilized in this analysis.

A review of these curves clearly indicates (based upon the assumed multi-stage model) that for a given level and duration of exposure, the younger population groupings incur a significantly larger percentage of their lifetime cancer risk relative to older segments of the population. Generally, a majority of a typical population's risk of environmental carcinogenesis is manifested in the 35 and younger age group.

CALCULATION OF RISK

The risk calculation for the exposed population addresses three specific conditions with respect to remedial alternatives. Under the no-action alternative, the estimate for cancer risk is simply the population at risk multiplied by the cancer risk estimated by the CAG procedures. Carcinogenic effects are assumed to be additive for purposes of this analysis. The results of this calculation indicate that the expected number of lifetime cancer incidents is approximately 14 over 70 years if no action is taken to remediate the off-site migration of hazardous wastes. This initial estimate for risk under the no-action alternative provides a baseline estimate from which to measure how effectively individual remedial alternatives reduce health risk.

The first remedial alternative considered for implementation involves the installation of a containment wall with provisions to isolate the contaminant sources and simultaneously pump contaminated groundwater from the aquifer system and treat the water prior to discharge. A profile for the levels of contaminant reduction based upon laboratory treatability studies and computer modeling of the aquifer system indicates that contaminant levels in the groundwater are represented by a step function with existing levels remaining relatively constant for 10 years and then decreasing to approximately 10% of the current levels. The levels remain unchanged for the 20 years that the system remains operational. The initial 10-year period that the system does not impact upon groundwater quality reflects the fact that contamination has spread beyond the influence of the remedial system; a period of time must elapse before any improvements are noted in groundwater quality.

The implementation of this remedial alternative results in the reduction in the expected level of risk. Based upon the application of the multi-stage model and the assumed population distribution, it is estimated that the expected number of cancer incidents would be approximately 3. This number must be adjusted for the risk which is incurred following the 30-year remedial action program, recognizing that there will be residual contamination in the groundwater. It was estimated that this residual risk was equivalent to approximately 1 additional incident of cancer. This value must be added to the projected 30-year risk associated with the groundwater containment and treatment system which results in a final risk level (expected number of cancer events) equivalent to approximately 4.

A similar analysis was conducted for the second remedial alternative based upon groundwater extraction and treatment but with no provision for the containment wall. This remedial option, like the previous alternative, had no influence upon groundwater quality for the first 10 years following installation. The improvement in groundwater quality was modeled as a step-function with contaminant levels decreasing to 70% of the initial level during years 10-20 following installation of the system and to 40% of the initial value during years 20-30. The final level of contamination was evaluated at 10% of the initial value and the improvement continued for years 40-70.

The risk associated with this alternative was equivalent to 5.0 expected incidents of cancer associated with the 30-year operation

of the system. To this, one must add the additional risk associated with the residual groundwater contamination for years 30-70. The addition of this incremental risk resulted in a total expected risk for the groundwater treatment alternative of approximately 6.0 incidents of cancer.

COMPARISON OF REMEDIAL ALTERNATIVES AND EXAMINATION OF COST-EFFECTIVENESS

The individual risk associated with the three remedial action alternatives can be compared to assess the cost-effectiveness of options which employ the application of technology to reduce the expected incidence of cancer associated with the implementation of remedial action technology. The baseline level of risk associated with the no-action alternative was estimated at 14 cancer events in the exposed population based upon application of the U.S. EPA CAG estimates for carcinogen potency. The residual risks following implementation of the groundwater coninment and treatment system or the groundwater containment system were 4 and 6, respectively. Therefore, the number of predicted cancer events avoided following implementation of the two technology-based remedial alternatives are 8 and 10.

This information about public health risk should be utilized to assist decision-makers regarding selection of appropriate remedial alternatives. However, there is no consensus among the scientific community regarding the approach which should be employed to formally introduce risk-based calculations into the identification of cost-effective remedial action programs.

A critical element in introducing risk-based calculations into decisions regarding public health risk centers upon our inability or unwillingness to place a numerical value upon mortality and morbidity. There is an entire field of literature based upon alternative procedures to monetarize mortality and morbidity, but there is no consensus regarding the most appropriate method to develop such measures.

The approach used in this analysis examining how monetary considerations for public health risk can be factored into selecting remedial alternatives is shown in Fig. 4. Here, a plot is made of the number of public health incidents avoided versus the present value cost of remedial action at a hazardous waste site where groundwater contamination poses a public health threat. Overlain on the plot is a series of curves representing the costs associated with each avoided incident. Depending upon the severity of the incident (mortality vs morbidity, for example) the associated costs of avoidance were represented as ranging from \$100,000 to



*Range of Costs Per Incident Avoided

Figure 4 Present Worth of Dollars Expended for Remedial Action (Millions)

\$2,000,000 per event.

The analysis proceeds by examining the relationship between the number of incidents avoided and the costs to implement the specific technology which leads to the avoided events. The number of incidents avoided for the proposed remedial alternatives are 10 and 8, respectively, for the containment and treatment option and the treatment option. The costs associated with the implementation of the remedial technologies are represented as a range (to reflect uncertainty) shown in Fig. 4. The cost per incident avoided can be examined by constructing a line from the number of incidents avoided which intersects with the range of costs for the associated technology.

The range in costs per incident avoided ranges from approximately \$1.6 to \$2.2 million for the containment and treatment option which results in 10 avoided incidents. Alternatively, the groundwater treatment option, which results in 8 avoided incidents, has an anticipated range in costs from \$0.9 to \$1.1 million. A comparison of these costs per incident avoided suggests that the types of remedial action proposed for this hazardous waste site are in the upper range of the costs per incident avoided as displayed in Fig. 4.

It is also noteworthy to compare the incremental or marginal cost associated with the per incident avoided costs when implementing the more costly containment and treatment remedial program. The two additional incidents avoided could have a cost ranging from \$2.5 to \$6.5 million depending upon the exact cost for each remedial alternative. These per incident costs far exceed any of the per incident costs plotted on Fig. 4.

This raises the question of whether it is cost-effective to expend the marginal costs of \$2.5 to \$6.5 million required to increase the number of avoided incidents by two. It would be difficult to justify this type of decision based solely upon consideration for the cost of incident avoided. There may, however, be additional factors which could support the decision to expend the additional funds.

These factors relate to issues of implementability, performance, reliability, environmental impact and safety. Each consideration can impact upon selection of the remedial alternative. These issues were not explicitly quantified in this analysis and will be addressed to future work.

CONCLUSION

This analysis has demonstrated that it is possible to provide for explicit considerations of quantitative risk assessments when evaluating remedial action alternatives for implementation at hazardous waste disposal sites. The comparison between remedial options can be made on risk-based criteria with consideration of the costs associated with incremental reduction in risk. Assessments must be made of the costs associated with the avoidance of a given incident. However, once a range of costs for avoidance is established, it is possible to identify the most costeffective remedial alternative.

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Risk and Exposure Assessment of an Abandoned Hazardous Waste Site

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INTRODUCTION

Site Description

The Sylvester (aka "Gilson Road) site in Nashua, New Hampshire (Fig. 1), was a former sand and gravel pit where hazardous wastes were dumped openly and illegally along with solid wastes from the late 1960s until November 1979. Solid waste, drums of hazardous waste, bulk materials and liquids covered about 3 to 4 acres. Although various consultants who have worked on the site used a figure of about 240,000 lbs for the total weight of waste deposited (based on 800,000 gal which was assumed to be over 96% water and exclusive of drummed surface waste), the total could well be 30 times this figure.^{3,7} Like many illegal sites, however, the quantity can never be known with any precision or confidence, because few records exist.

The Sylvester site is located outside the town of Nashua off Route 111. Immediately adjacent to the site are two mobile home communities and a small tributary (Lyle Reed Brook) to the Nashua River. In the fall of 1982, a 6.2 acre cap and a slurry wall were constructed. In 1984 the state began construction of a groundwater recirculation and treatment system which began operating in 1986 and is expected to achieve its goals in 2 years. This analysis will consider the site conditions both before and after these remedial activities.

Risk Assessment Overview and Context

As recently defined by the National Academy of Sciences,⁶ risk assessment is:

". . .quantitative and qualitative evaluation of human health risk from environmental exposures and includes the uncertainties associated with model assumptions used in inferring risk."

There is a wide variety of definitions of risk assessment including the evaluation of physical hazards such as ionizing radiation and floods. For the purpose of evaluating hazardous waste sites, risk assessment has been defined by one expert⁵ as:

". . .the systematic scientific characterization of the probabilities and types of adverse effects that may result from chemical releases at the site."

Regardless of the definition, risk assessment methodology generally includes the following four elements:

- *Hazard Identification*—Involves gathering and evaluating data on the types of health injury or disease that may be produced by a chemical and the conditions of exposure under which injury or disease is produced.
- Exposure Evaluation—Involves describing the nature and size of the population exposed to a substance and the magnitude



and duration of the exposure. Exposure is used as an indicator of dose.

- Dose-Response Evaluation (Toxicity Assessment)—Involves describing the quantitative relationship between the amount of exposure or intake (as an indicator of dose) to a substance and the extent of toxic injury or disease.
- Risk Characterization—Involves the use of the data and analysis from the first three components to determine the likelihood that adverse health effects will occur in the exposed population associated with that exposure. In cases where exposure data are not available, hypothetical risk can be characterized by use of hazard identification and dose-response evaluation data alone.

The purpose of this paper is to apply this methodology to examine the effect of exposure assessment variables on the risk characterization outcome. Uncertainty is perhaps the foremost certainty in environmental risk analysis. Despite the uncertainties, however, useful risk analyses can be developed by estimating reasonable ranges of risk estimates and by using techniques such as sensitivity analyses and worst case assessments. Both the basis and the result of various exposure assessment variables will be explored. Because evaluation of all potential routes of exposure is beyond the scope of this paper, only one surface water route and one air route will be considered.

SOURCE CHARACTERIZATION

Waste Characterization

Although there are almost no records concerning the quantities and types of wastes that were disposed, some insight on their nature can be obtained from information documented during an inspection of the drummed wastes and groundwater contaminants. The majority of the liquid wastes were comprised of volatile organic solvents including mixtures of aliphatic ketones and esters, alcohols, substituted aromatics and volatile chlorinated solvents. Many of the waste liquids were similar in appearance and odor to various paint thinners, varnish, petroleum products and paint products. Infrared spectrophotometer analyses indicated the presence of alcohols, benzenes, toluenes and xylenes. Toluene and xylene were the predominant chemical constituents. For most of the waste solvents, the vapors were easily detectable. Another group of wastes were chemically classified as organic still bottoms, consisting of organic polymerized by-product residues from polyurethane foam production. The contaminant most often found in groundwater at the highest concentration is tetrahvdrofuran.

Tetrahydrofuran (THF) often is found as an artifact in chemical analyses because of its use as a plasticizer. Because THF may leach out of polyvinyl chloride (PVC) monitoring well tubing, artifact THF usually is found at higher concentrations in new wells than in old wells. Also, THF concentrations tend to decline over time in a newly constructed well. Finally, if the artifact occurs as a result of analytical apparatus (e.g., tubing) rather than PVC monitoring wells, and, if analytical procedures are consistent for all wells, then the THF concentrations are uniform across wells in many locations. Because tetrahydrofuran was found in high concentrations in the groundwater (3,000 mg/l) from wells of a variety of ages but localized to certain locations, it is not believed to be an artifact.

No pesticides or PCBs were encountered in the sampled drums. This negative observation is important because these chemical groups are more persistent and tend to bioaccumulate more than most other substances found at hazardous waste sites, and because disposal costs for PCBs may be twice as much as standard RCRA-hazardous waste.⁸ These analyses of drummed wastes are not necessarily indicative of the wastes at the site. Wastes also were disposed in bulk on the surface and through a makeshift pipe. These other methods may have accounted for most of the waste disposed. The lack of information on the nature and extent of the contaminant sources is probably the most significant data gap in the risk assessment of this site. The estimates of the wastes on-site will be discussed further below.

Release Estimation

Contaminated groundwater from the site flows northwesterly toward Lyle Reed Brook, which is about 680 ft from the site and flows into the Nashua River. Groundwater, sampled at test wells downgradient of the site and upgradient of Lyle Reed Brook (e.g., HB-2), contained up to 123 mg/l methylene chloride, 31 mg/l chloroform, 330 mg/l trichloroethylene, 1.7 mg/l arsenic, 640 mg/l iron and 115 mg/l manganese. Although the concentrations of these contaminants in surface waters were substantially lower than those found in the groundwater, they were adequate to eliminate all macrobiotic stream life and to cause a nuisance to nearby trailer park residents from odorous air emissions.

Sometime before 1981, the top of this leachate plume seeped into Lyle Reed Brook which, via the Nashua River, is a tributary of the Merrimack River (Fig. 1) and provides drinking water to the towns of Lowell, Lawrence and Methuen, Massachusetts.⁷ The plume of contaminated groundwater at the Sylvester site was estimated in January 1982 to be roughly 30 acres in area, 1,500 ft long and 100 ft deep. This is approximately five times the size of the actual site area (6 acres) and almost ten times the size of the original disposal area (3-4 acres). The nature and size of the plume varied with the concentration and type of pollutants measured.

For volatile organics, a lobe of the plume extended considerably beyond Lyle Reed Brook in January 1982 before the use of the groundwater recirculation system. This lobe of the plume was measured at 10 mg/l of total volatile organics beyond Trout Brook Road, at least 800 ft beyond the edge of the site. The source of the plume of volatile organics was centered at the subsurface leaching trench leading from the rear of the C&S Disposal Company Garage.

In late 1980 the "metals plume" (total summed metals at greater than 1 mg/l) extended beyond Lyle Reed Brook. At the same time, the volatile organics plume had not yet reached Lyle Reed Brook. This suggests that, because metals typically travel slower than organics, they were in the ground longer than the organics. In addition, because the metals plume source appeared to be centered on the eastern edge of the site about 400 ft from the infiltration drain leading from the garage, it may have emanated from another source.

The leachate discharge from the site originally was estimated at about 88,000 gal/day. Following construction of the slurry wall and cap in fall 1982, this flow rate was reduced to 30,000 to 55,000 gal/day. Because the flow rate was expected to be reduced to 6,000 gal/day, groundwater is believed to be flowing under the slurry wall through fractures in the bedrock or through the slurry wall due to corrosion.^{1,4} Of the groundwater flowing off-site, about one-third was expected to breakout into Lyle Reed Brook, while an additional one-third was predicted to flow into Trout Brook.

Initially, the three primary potential public health threats caused by the site were: (1) the contamination of the Merrimack River, which is used as the drinking water source for the town of Lowell, Massachusetts. The state predicted that at the Lowell town pumping station the water quality criteria for arsenic (2.2 ng/l) would be exceeded by a factor of 6.8^7 ; (2) the threatened contamination of several private drinking water wells at houses along Route 111 by the plume of contaminated groundwater, which migrated at about 1.6 ft/day; and (3) an air pollution problem caused by chloroform volatilization from Lyle Reed Brook into the nearby trailer park at ambient levels exceeding chronic lifetime exposure limits (MEGs). In addition to these public health threats, an odor nuisance was created by volatilization of organics (primarily diethylether and dimethyl sulfide) from Lyle Reed Brook.

The residents of Jensen's Trailer Park are not dependent upon local groundwater resources for drinking water because they are served by a municipal system. The residents along Route 111, however, who are in the path of the contamination plume, use private wells for their drinking water. Because these eventually were expected to be contaminated, the houses were connected to city water from a distant municipal well in 1981. Other nearby private wells, such as the Pennichuck W.D. well, were not in use. The expected arsenic contamination problem was discounted later because naturally high arsenic concentration made this apparent contribution insignificant.

In addition to determining the amount and routes of release, the releases should be characterized chemically. Again, because the source material is not precisely known, the groundwater will be assumed to be the source. All groundwater monitoring analysis results logs were entered onto an IBM "Lotus 1-2-3" spread sheet, and means, median and maximum concentrations were determined. To facilitate further data management, chemicals were separated into three groups (A, B and C) according to their maximum concentration (see groups A and B listed in Table 1).

			Table 1			
Chemicals	Found	in	Groundwater	at	Sylvester	Site

Gr (1,	oup Α 000 μg/l)	Group B (1 μg/l to 1,000 μg/l)
35 20 28 5 12 10 13	acetone benzene chlorobenzene chlorothane chloroform 1,1-dichloroethane 1,2-dichloroethane	 30 bis-chloromethyl ether 16 bromodichloromethane 24 bromoform 15 carbon tetrachloride 21 2,1-dibromochloromethane 17 1,2-dichloropropane 18 trans-1,3-dichloropropylene
9 29 41	1,1-dichloroethylene ethylbenzene ethyl ether	22 cis-1,3-dichloropropylene25 hexachloroethane4 vinyl chloride
36 6 37 39 26 33 27 14 19 34	isopropyl alcohol (IPA) methylene chloride (MeCl) methyl ethyl ketone (MEK) methyl isobutyl ketone perchloroethylene tetrahydrofuran toluene 1,1,1-trichloroethane trichloroethylene (TCE) xylene	- -

EXPOSURE ANALYSIS

Exposure analysis is perhaps the most important step in exposure assessment—partly because it is the least understood—but also because it can dramatically affect the final risk characterization through relatively small changes in assumptions. The two basic steps: (1) identify exposure pathways and (2) estimate exposure point concentrations, provide a systematic method for evaluating exposure. Although this method does not eliminate uncertainty, it does assist in organizing and analyzing existing data, elucidating specific data weaknesses and providing the data necessary to evaluate the exposures in the next steps of the risk assessments.

On the basis of the exposure analysis, it is possible to evaluate the primary sources of uncertainty regarding estimates of exposure concentrations. A general paucity of data plagued many estimates. But, specific sources of uncertainty include the following:

- Source characterization (nature and amount)
- Discharge rate from source
- Attenuation of contaminants (volatilization, hydrolysis, etc.)
- · Receptor location and intake

The nature and extent of the source and discharge from the site are described briefly above in the site description. The lack of data regarding contaminants and site conditions prevented a more precise treatment of contaminant attenuation. Finally, receptor location and intake quality are probably the greatest areas of uncertainty—e.g., will the site be used following cleanup?

Potential exposures to volatile organic chemicals may occur from the air, groundwater and surface water. The highest potential exposure concentrations from the site probably would be from ingestion of contaminated groundwater. Actual intake quantity should be insignificant in the near term because groundwater use is unlikely. Groundwater on the site likely will not be used for several decades because the state owns the site and will control access and use. Beyond a few decades, however, these institutional barriers may prove ineffective, while the site may remain highly contaminated. The risk analysis framework is useful for identifying, quantifying and evaluating all potential exposure pathways, however unlikely, in the near term.

Identify Exposure Pathways

Table 2 shows the possible human exposure points. Although certain points are very unlikely sources of exposure (e.g., on-site wells), they are included here for completeness and to demonstrate a point about receptor uncertainty.

Estimate Exposure Point Concentrations

Estimating exposure point concentrations is the most complex part of the exposure assessment for two reasons. First, the estimation typically involves mathematical modelling of pollutant transport and fate, which often requires extensive data collection efforts. Second, estimating exposure involves manipulation of a massive amount of data. To simplify this paper, only two exposure points—Nashua River contaminant concentrations and ambient air above Lyle Reed Brook—were considered. Worst case data and situations will be used, but the results should be placed in perspective with the necessary qualifications.

Nashua River at Trout Brook

The predicted concentration of Group A contaminants in the Nashua River where Trout Brook enters are presented in Table 3. These estimates are based on a dilution factor from Trout Brook (d = 111) and appropriate half-life values. This d-value from Trout Brook is used instead of the minimum cumulative dilution factor (using the highest breakout rate) from the breakout zone at Lyle Reed Brook (12,866) for simplicity. By using the Trout Brook contaminant concentrations, the previously calculated effects of volatilization (from the Lyle Reed Brook breakout zone) and other attenuation effects (using the half-life values) automatically are considered. One-third of the contaminated groundwater flowing off-site was estimated to be breaking out into Lyle Reed Brook.

The dilution factor is determined by dividing the average flow rate of the Nashua River by the discharge rate from Trout Brook. The flow rate (597 ft³/sec) of the Nashua River used was a mean of 5 years of records (1975-1980) from the U.S. Geological Survey. For calculating the attenuation of the contaminants using the half-life value, a distance of 1,400 ft and a flow velocity of 53.4 ft/min (76,896 ft/day) or 0.02 days travel time between Lyle

Reed Brook junction with Trout Brook, or Nashua River were used. For predicting contaminant concentration at the specific locations (Nashua River at Trout Brook), instantaneous and complete homogeneous mixing was assumed.

 Table 2

 Possible Human Exposure Points

A. Ground Water		a. Suctara Mat	er EAir	S. AIR		
	On-site valls (Pennichuck	a. Lyie Re	ed Brock #.	Lyis Reed Brook		
	W.D. WEIT)	b. Trout B	raek b.	Jensen Trailer Park		
b .	Existing off-site vells along Route 111	e. Haahua	River			
е.	Downgradient vells	d, Marrina Lovell,	ok River et NA			

Table 3 Dilution Concentration in Nashua River at Trout Brook for Group A Chemicals

	Concentration in Irewi	Nextwork	_Qencent.re		abus River	Balfal.	IVER (Ger	<u>81</u>
	11.000 mm (A1)	(100/L]	11/2 100		11/2 high	Lex	Rish	8*
17028	ecetone benzone chile robenz i ne	4, 167 50 46	0.44 0.41	37.54	0.45	1.00	6.00	\$
7 12 10	chierestane chierefere 1,1,-DCathane 1.2-dichierstane		1.42 0.23 0.10	0.94	1.63	0.30 1.00 9.17	80.00 5.00	Å
9 89	1, 1-DCE sthylbenzens sthyl sther	14 370 500	0.13		8.13 3.13	1.90	6.00 7.50	Å
4 37 39	MaCi NEX asthyl (sebuty) hutone	1,021 1,000 277	9.08 8.11	2.50	9.19	1.20	5.80	
26 33 27	perchierosztyłana zezratydrofuran zelwone	12,500	0.08 7.49	118.61	0.06	1,00 9,17	30.00	
ii.	TCE nylone	12 76	0.11		0.10 8.07	1.00	90.00	i

Sources of half-life and other physico-chemicals data: A. ECAO, U. S. EPA, 1985. Health Effects Assessment for specific chemical. B. OSW, U.S. EPA. 1984b. Exposure Profiles for RCRA Risk-Cost Analysis Model, Prepared by Environ Corporation.

Using the worst case concentrations (highest) from Trout Brook, the contaminant concentration predicted for the Nashua River at Trout Brook was calculated using both low and high half-life values. The low half-life value was used in addition to the higher value because the relatively greater biological activity in the lower sections of Trout Brook makes this value more relevant than it was for Lyle Reed Brook. In those cases where no half-life was available, simple dilution was used. These values are listed in the middle column to show that they are neither the high nor the low half-life value. In those cases where only one half-life value was available (low or high), only that value was listed (see chlorobenzene).

Of the 20 Group A contaminants, one-half are predicted to have concentrations greater than $1 \mu g/l$. Two (isopropyl alcohol and tetrahydrofuran) are predicted at greater than $100 \mu g/l$. The remaining 10 contaminants are predicted to be below $1 \mu g/l$ in the Nashua River at Trout Brook; this is regarded in this analysis as the cutoff point for significant concentrations, partly because this is the level at which accurate analysis can be obtained using stan-

Table 4					
Ambient Air Contaminant Concentration					
at Jensen's Trailer Park (ppb)					

	Hestinum Air Cone. June 1961 Locations #005/006 	N20 Cone, Well NB-2 	H20 Conc. Rexiaus (us/L)	Entropo- loted Air Cono. iath]_		Estimated Air Cane, (ms/ml)_(mm)	
benzene chioroferm methyi ethyi ketene tetrekydrofuran toiuene vinyi chioride	4,8 MD 13,6 0,4 MD	7 ND 2,900 100 ND	6,360 31,000 120,000 130,000 100,000 7,320	4, 341 8, 049 800	0.10 0.11 8.6K-J	1.8	0.38 0.70 0.39 2.3

a Based on three hour integrated sample

b. Groundwater concentrations are drawn from Sept. 1981 and Jan. 1982

Henry's Law Constant

d Estimated head space air concentration. Exposure concentrations would be much lower (10 to 100 times)

dard GC/MS, but also because this is the level below which most chronic effects are considered insignificant for most exposures. All Group B chemicals are at least an order of magnitude below this 1 μ g/l cutoff. Therefore, Group B chemicals were not considered further in the downstream dilution analyses.

Jensen Trailer Park

The potent exposure concentrations at Jensen's Trailer Park from volatilized contaminants from Lyle Reed Brook were more difficult to estimate than those just above Lyle Reed Brook. Table 4 shows the predicted ambient air concentrations using two different methods.

First, the ambient air concentrations of contaminants volatilizing from Lyle Reed Brook were estimated roughly using weekly air sampling data performed in June 1981. Because the concentrations reflect only a snapshot in time at a relatively early period of the site history, it is necessary to attempt to predict future concentrations. The air was sampled at a variety of locations. The maximum concentrations all were found at the breakout zone (locations GRS 005, 006). Higher air concentrations could be expected because the groundwater concentrations at the well closest to the breakout zone (HB-2) were relatively low at that time compared to concentrations found at later times.

Future concentrations of the contaminants were predicted by extrapolating the measured concentration with a ratio of groundwater concentrations. The assumption was made that the Lyle Reed Brook breakout was the only source of volatilization. For example, soon after the maximum THF concentration (32.8 µg/) was sampled in air (June 1981), the groundwater at well HB-2 was found to be contaminated with 2,900 µg/l THF (Sept. 1981). In January, the THF concentration at well HB-2 increased to 20,000 $\mu g/l$, then the January air concentration could be extrapolated to be 262 μ g/l (20,000/2,500 × 32.8). Of course, the cold temperature during January probably prevented any volatilization (or sublimation). However, subsequent summer air concentrations may have paralleled the groundwater concentration increase. The maximum THF groundwater concentration on the site was 1,500,000 μ g/l, which represents a 600-fold increase over the June 1981 HB-2 concentration. Similar linear extrapolations for several other contaminants are shown in Table 4.

For most of the contaminants sampled in 1981, an extrapolation was not possible because of a lack of data. Only 5 of the contaminants analyzed in the air in 1981 were found in the air and in the groundwater at that time at HB-2. Six of the 14 contaminants analyzed in the air were not detected, and of these only one (methyl isobutyl ketone) was found in HB-2. Another contaminant (1,1-dichloroethylene or vinylidene chloride) was found in the air at an extremely low concentration (0.1 μ g/l) but not in the groundwater at HB-2. Hence, absence or presence of a contaminant in the air correlated well with an absence or presence of a contaminant in the groundwater at the closest well (HB-2).

The assumption used in the above extrapolation was tested using a second methodology. The well head space air concentrations were estimated for four contaminants using their Henry's Law constants. The resulting concentrations, given in the last two columns of Table 4, show the estimated air concentration that would be predicted at STP in the well (or sampling jar) head space from the unimpeded volatilization of those contaminants at their maximum observed water concentrations. Hence, dispersion from this maximum saturated concentration would be expected to be much lower for downwind exposure locations by one to three orders of magnitude. In each case where a comparison is possible, the estimated head space air concentrations. This anomaly may be due to other air sources contributing to the measured air concentrations, interferences from other organic compounds during the sampling or surface water concentrations that were higher than observed during the actual air sampling period.

FINAL STEPS

The final steps of a risk assessment—intake estimation and risk characterization—are beyond the scope of this paper except to describe in general terms. Intake is used as a surrogate for actual toxicological dose because of the complexities of calculating dosages. For estimating drinking water intake, standard assumptions (a 72 kg adult drinking 2 l of water daily) are used to determine the dose (mg/kg) from water concentration (mg/l). Similarly, a dose is estimated for children (10 kg) and adults (70 kg) breathing about 5 and 20 m³/day, respectively.

Risk characterization is at least as complex as exposure assessment. A "potency factor" for each chemical and route of exposure (oral ingestion, inhalation and dermal contact) can be used to determine a cancer risk probability associated with observed or predicted levels of exposure. The U.S. EPA's Carcinogen Assessment Group has derived several potency factors which are listed in the U.S. EPA's draft Public Health Assessment Manual for Superfund.

Shortcomings include: (1) the limited number of chemicals for which potency factors have been estimated; (2) the limited outcomes for which estimates are performed (e.g., cancer); and (3) well-documented uncertainties regarding extrapolations from animal data.¹

CONCLUSIONS

The results of this type of analysis may be used to make multimillion dollar decisions affecting thousands of people for several generations. Because the results of each step feed into the next step, it is important that any assumptions used are reasonable. In the case of this exposure assessment there were two major uncertainties. First, there were data gaps such as source characterization and exposure concentrations. Second, the future receptor locations (on-site, downstream, down wind) were uncertain. Resolution of these problems will require that the health assessment professionals work closely in design and execution of the data collection efforts during the remedial investigation.

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Death or Cancer—Is There Anything Else?

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INTRODUCTION

Americans seem to have a mental fixation on cancer and death. As a result, many emergency response actions focus on death and cancer to the exclusion of other public health concerns. The news media, using information provided by members of the emergency response group, can create public reactions to toxic releases that are out of proportion to the actual health threat. Environmental and health professionals must respond to the public's concern, but are we guarding the front door of the chicken coop while the fox is slipping in the back door?

I believe that, as professionals involved in environmental and health activities, we are not fully protecting public health and preventing human suffering if the primary health concerns during a release of hazardous substances are death and the risk of cancer. This paper first discusses why some believe these two outcomes are often the primary health concerns, and then reviews what health effects may be ignored or at least accorded lower priority.

PUBLIC PERCEPTION

One of the main objectives of the news media is to inform the public; but another objective is to assure the continuation and, hopefully, the growth of some form of rating of their popularity. These two objectives are interrelated. For example, if a television news program does not report a hazardous substance release and do it in an interesting way, viewers may turn to another station. The result of this is that news must be presented in a way that catches the public's attention. Career advancement and income of reporters, photographers and cameramen in news departments depend in part on how much of their material is used and whether it is "above or below the fold." Who wants to read that nothing frightening, dangerous or exciting happened today? If there is a possibility that the release of a hazardous material threatens people or property and some aspect of the release might be frightening to the public, that aspect of the information will be (and should be) reported.

There are strong institutional forces seeking to discover or create controversy and public interest. Environmental and public health professionals have very different agendas from news professionals. This statement is not made to condemn news media, it is simply stated to show how they work and the limits placed on their reporting.

Information and education are two different concepts. The methods used to inform and educate are different, and so are the results. The public must be both informed about emergency response needs and educated about emergency preparedness and contingency planning. They must know if they need to respond to a hazardous substance release, what level of response is appropriate to the situation and how to react.

People's perceptions of risk often are inaccurate and these perceptions are influenced by factors such as the memory of past events and imagination of future events. Studies by Lichtenstein, Slovic and Fischhoff' and others have shown that dramatic and sensational causes of death, accidents and cancer tend to be overestimated. Risks from undramatic health problems like emphysema, skin irritation or infected cuts tend to be underestimated, even if they cause greater suffering and loss of workdays.

News coverage often reflects this tendency and may contribute to the public's perceptions of what are the greatest risks. Table 1 shows how the biases in news coverage in two different newspapers parallel biases in perceptions. Fig. 1 graphically illustrates this hypothesized relationship.

The public's perception of risk is likely to strongly affect their reaction to news of a toxic release and what they might demand

Table 1 Statistical Frequency and Newspaper Coverage in Two Newspapers for 41 Causes of Death

. .

		8	ate per		Repor	C 80
		20	5 Million	Subjects'	Death	5
Caus	e of Death	Ų.S.	Residents	Estinates	A	8
1.	Smallpox		0	57	0	0
2.	Poisoning by vitami	n #	1	102	0	
3.	Botulism		2	183	0	0
4.	Measles		5	168	0	0
5.	Fireworks		6	160	0	0
6.	Smallpox vaccinatio	n		33	0	0
7.	Whooping cough		15	93	0	0
8.	Polio		17	97	0	0
9.	Venomous bite or st	ing	48	350	0	Q
10.	Tornado	•	90	564	36	25
11.	Lightning		107	91	1	0
12.	Non-venceous enimal		129	174	4	2
1).	Flood		205	736	4	10
14.	Excess cold		334	314	0	0
15.	Syphilis		410	492	0	0
16.	Pregnancy, birth, a	bor.	451	1,344	0	0
17.	Infectious hepatiti		677	545	0	0
18.	Appendicitie		902	605	0	0
19.	Electrocution		1.025	766	5	0
20.	MV/train collision		1.517	689	0	1
21.	Asthma		1,886	506	1	0
22.	Firearm accident		2.255	1.345		1
23.	Poison by solid/lig	blu	2.563	1.013	3	3
24.	Tuberculosis		3.690	658	Ó	0
25.	Fire and flames		7.380	3, 336	94	46
26.	Drowning		7.380	88.000	47	60
27.	Leukemia		14.555	2.496	1	0
28.	Accidental falls		17.415	2.675	15	1
29.	Nomicide		18.860	5.582	270	208
30.	Emphysens		21.730	2.848	- i	0
31.	Suicide		24.600	4.679	29	15
32.	Breast cancer		31.160	2.964	0	0
33.	Diebetes		38,950	1.476	ŏ	1
34.	Notor vehicle accide	ent	55.350	41.161	298	63
15	Lung Cancer	••••	75 850	9 744		2
36.	Stonach cancer		95.120	1 281	ň	ī
17.	All accidents		112.750	AR 879	715	594
18.	Stroke		209.100	7 109	1,2	
19	All cancer		128.000	45 609	17	
40	Neart disease		718.000	33,007	23	10
41	All disease		740.450	A		17
		-•			***	• '
Total	number of reports	Cause	10 29, 31,	37, 41)	1113	910

Source: Combs, B. and Slovic, P., Journalism Quart., 36, 1979, 837.



Figure 1

Hypothesized relationship between media coverage (size of dot) and nature of the hazard. Hazards perceived as unknown and dread would receive greater coverage than other hazards. (Adapted from Slovic, P., "Informing and Educating the Public about Risk." In press.)

of their public health officials. A mathematical technique called factor analysis arrays characteristics the public uses to describe hazards (Fig. 2). It is clear that chemicals in general, and specific hazardous materials in particular, all are viewed similarly. Hazards at the top were described as not observable, unknown to those exposed, effect delayed, new risk and risks unknown to science. Likewise, those along the right side were considered uncontrollable, dreaded, catastrophic, fatal, not equitable, and so forth, as shown for Factor 1.

UNCERTAINTY IN ENVIRONMENTAL HEALTH SCIENCE

One of the greatest difficulties in tieing actions to concerns about cancer is that if an exposure were to cause cancer, the disease probably would not appear clinically for years or even decades. To overcome this time delay of cause/effect relationships, we have come to rely, in part, on statistical models derived from high-dose experiments with animals. When the weight of evidence is considered, the U.S. EPA Cancer Assessment Group, the International Agency for Research on Cancer or another agency assigns a level of risk to a chemical. For example, a chemical may be designated a possible human carcinogen, a probable human carcinogen or a human carcinogen.

The modeling process introduces many uncertainties and policy choices that may be hidden in the technical intricacies of the mathematics of modeling. A recent article reported that bioassay data were fit to four analytical models used to estimate cancer risk: logit, multistage, probit and Weibull. These four models are representative of models currently in use. There are no biologically based criteria for choosing one model over another and no assurance that the predicted risk lies in the range predicted by the model. All models used the same base: 50 μ g/l trichloroethylene in drinking water. For one model the risk estimate is about 10^{-2} , whereas with another the estimate is 10^{-10} . This means that the estimated risk of excess cancer in a population exposed to this level of TCE for 70 years (assuming ingestion of 2 l of water per day) would range from one per hundred persons exposed to one per ten billion persons exposed. These estimates provide a range of uncertainty equivalent to not knowing whether one has enough money to buy a cup of coffee or pay off the national debt.

The rationale for using the most widely used model is that it is unlikely that its risk number underestimates the true risk. Results usually are given only as an upper bound estimate of risk (95%upper confidence limit on the probability of a response). There are several difficulties in relying solely on the 95% upper confidence limit on risk:

- The upper confidence limit on risk may be very much larger than the estimate of risk
- The lower bound estimate of risk from the model may be zero, that is, there is no excess risk
- These models produce the least accuracy and precision at the low dose levels extrapolated from animal data; these are the levels of environmental exposures.
- With this model, the upper bound on the risk can be small when the estimate of risk is small or when it is not small. Thus one cannot tell if the bounds are extremely conservative of defined health effects or if they are only slightly conservative.

The sole reliance on this numerical estimate of risk may lead to large expenditures of effort and money without any assurance that this protects public health any better than a lesser effort.

The credibility of scientists may be challenged when the public hears or sees that the experts appear to disagree strongly about the risk from a chemical release. One problem is the difference between the process of science in reaching consensus about a question and the process of law which sets two opposing views of expert witnesses at the opposite extremes.

The legal need for relative certainty and probable cause drives expert opinion to opposite extremes of a question, whereas the scientific process leads to general agreement and consensus.

Another source of uncertainty at a hazardous substance spill site is the estimate of human dose. Many assumptions are made for inhalation, skin absorption, ingestion and absorption in modeling total body uptake. These assumptions often rely on average values which may not represent the situation at hand. For long-term exposures, one has the luxury of time to measure the critical parameters, but at a spill site (for example at a truck or train derailment), speed in response is often critical. I believe that one source of uncertainty can be reduced greatly by testing environmental levels of the chemicals where the population at risk is located, as well as at the site.

Input from a health scientist can determine the specific needs on a case by case basis. Without the kind information that a health scientist knows how to gather best (i.e., human exposure data and symptoms to look for), the health outcomes reported at these sites will continue to be, "no one died, so we must have done the right thing." It is difficult to find an unexciting effect if no one looks for it.

DIFFERENCES IN RISK PERCEPTION

The scientific community which responds to releases of hazardous materials must understand better their own as well as the public's perceptions of what constitutes a certain level of risk. We can be reasonably sure that all communities will not be alike in this, but how greatly they differ can be discovered only through more field research. Once we have a deeper knowledge of various perceptions of risk, we must improve communication of those perceptions among the involved groups. Greater and earlier public involvement in the process of risk evaluation may help.

Federal and many state agencies mandate or suggest that the public be a part of the planning or assessment phases of emergency and remedial response. Emphasis should be placed on seeing that the public truly has a chance for meaningful involvement. A number of states and federal agencies are channeling resources to the local level for research and training in risk communication.

REDUCING UNCERTAINTY IN RISK ASSESSMENT

We can improve the risk assessment process to make it more realistic in emergency response actions by:

- Developing and using physiologically based animal exposure models to derive dose response relationships; pharmacokinetic models currently under development try to account for response at the level of the target cells.
- Collecting better data on human exposure by improving and calibrating dispersion models; developing methods for more rapid collection and analysis of biological samples; improving and expanding data bases on background levels of chemicals in humans; and continuing to search for new methods to detect exposure, such as DNA adducts, subclinical physiological response and nerve conduction tests.
- Expanding our knowledge about dose/exposure responses in animal exposure tests to improve the validity and accuracy of interspecies comparisons.





Factor analysis of risk relationship among hazards. (Adapted from Slovic, P., "Informing and Educating the Public about Risk." In press.)

IMPROVING THE SITUATION

There must be more public education about the true risks from releases. Knowledge of the process and of how risk estimates are made will encourage appropriate risk reduction behavior and an accurate understanding and healthy amount of concern by the public about the potential danger of chemical release. The public should be neither apathetic nor panicked.

What then are some other issues that should be addressed? The public is not the only group whose health should be considered. Are the workers at the scene fully informed about the kind of risks that exist at the site? Should they be protected from skin irritation with proper protective suit? Is there a risk from lung and eye irritation that might result in eye damage, blindness or respiratory collapse? Is physical protection needed from falling and exploding objects? Is everyone wearing hard hats and protective goggles if needed? If a worker or victim is contaminated with a toxic chemical, do the ambulance crew and emergency room staff have proper personal protection equipment to treat the victim? Will the victim contaminate the ambulance and emergency room?

If we are going to try to change an individual's perception of threat and understanding of risk, it must be done before the problem occurs. This process must involve active planning for a hazardous materials release by all individuals who may be involved. Only then will they be prepared when a release occurs.

There are several key points in this idea. First, there must be "active planning." Preparation for a release is not something that can be done for someone, and it is not an activity that can be done in a vacuum. The city planning agency cannot guess how the health department will respond to a hazardous materials release, so both agencies must work together to prepare for the time when a release occurs. Almost everyone in the community should be a part of the planning team, and, just as in a sport, the team must practice to assure that each member knows his role and the responsibilities of the other players.

In preparing to respond to a release of hazardous materials, the response team must also develop an active cooperative relationship with the industrial community. Manufacturers, formulators and commercial users of chemicals in the area can provide expertise and information on their products. These companies also can supply emergency response equipment and trained personnel. Throughout the country, this type of cooperative relationship is helping to prepare for accidental chemical releases. This is particularly evident in the Community Awareness and Emergency Response (CAER) program of the Chemical Manufacturers' Association.

Another important partner on this team is the media. A partnership should be established with them, also. Biologists would classify this relationship as symbiotic; for each group, media and responders, needs the other and each will profit from the relationship. The media must inform the public of potential events, place the situation in proper perspective and advise the community of the actions to take when an event occurs. The response community must develop a trusting relationship with the media before the event.

The community also must become involved in the planning process. They must be aware of the risks from a chemical release and the plans for action that might be required. If they are to act appropriately, the community, the government, the media and the corporate groups must trust each other.

CONCLUSION

In a recent release, a large evacuation was ordered. However, based upon the perception of the problem by the community and their belief that the city was overreacting, many individuals did not relocate or they left the area and returned to their homes prior



Figure 3 Institutional Forces on Scientific Views in a Scientific Setting and a Legal Setting

to an "all clear" message. This early return to the danger area resulted in many residents placing themselves at increased risk.

We use the phrase "when an event occurs." It is not a question of whether an event will occur; a hazardous material incident will occur. The only factor is when. Contingency planning must be initiated and must extend beyond the scope of fire trucks, protective clothing and tank patches. It must extend to the community to increase the understanding of risk—total risk in its broadest sense. Preparation would include representatives from major groups and institutions to assure that response issues are addressed.

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Missouri Dioxin Studies: Some Thoughts on Their Implications

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ABSTRACT

In 1971, 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (TCDD)-containing sludge wastes were mixed with oils and sprayed for dust control on various residential, recreational and commercial areas in Missouri. By February 1986, 40 sites in Missouri had been confirmed as having at least 1 ppb of 2, 3, 7, 8-tetrachlorodibenzo-pdioxin (TCDD) in soil related to disposal of waste from a hexachlorophene production facility in Verona, Missouri. In order to investigate these TCDD contaminations, several studies have been undertaken.

Results of a pilot epidemiologic study recommended that additional studies looking at possible urinary tract, liver, neurological and immune system effects should be carried out. Results from a larger study of persons with exposure to TCDD in a residential setting reported in April 1986 showed that persons exposed to TCDD: (1) did not have any statistically significant increased prevalence of clinical illness diagnosed by a physician, (2) had no significant pattern of differences on medical history, physical examination, serum and urinary chemistry studies or neurologic tests, (3) showed some differences in liver function test results which may serve as a biological marker of exposure or as a sign of subclinical effects and (4) had an increased prevalence of anergy (11.8% vs 1.1%) and relative anergy (35.3% vs 11.8%) on immune testing compared with persons who were not known to have been exposed to TCDD. Repeat immunologic studies of persons with anergy and relative anergy are in progress.

Studies of adipose tissue from persons exposed to TCDD in occupational, recreational and residential settings also are in progress. Follow-up studies on the persons with adipose TCDD are underway. These findings suggest that additional studies are needed in order to develop a more complete understanding of the risks and appropriate public health interventions in situations of community exposure to environmental dioxins.

INTRODUCTION

Historical Perspective

In 1971 approximately 29 kg of 2, 3, 7, 8-tetrachlorodibenzo-

p-dioxin (TCDD)-contaminated sludge wastes, which originated as a by-product of hexachlorophene production in a southwest Missouri plant, were mixed with waste oils and sprayed for dust control throughout the state. Almost 250 residential, work and recreational areas (including several horse arenas) were thought to be contaminated, including the town of Times Beach. To date, approximately 40 sites have been confirmed as having at least 1 ppb of TCDD in soil. At first, levels as high as 35,000 ppb were measured in soil at one of these sites; at the time of these initial studies, isolated levels over 2,000 ppb existed in some contaminated areas, but most detectable levels in soil samples ranged from several hundred ppb down to less than 1 ppb.

About one-third of the confirmed sites were contaminated with peak levels in excess of 100 ppb; one-half of these were in residential areas. These sites varied widely in their potential for leading to human exposure due to the lack of uniformity in geography, topography, geology and characteristic land use. This variation has presented difficulties in the public health decision-making process. Sites at which the levels of contamination were high and which are in areas of frequent and regular access constitute the greatest public health risk; however, at other sites, dioxin contamination was 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 5,000 individuals from these contaminated areas during the period from 1971-1983.

The earlier phases of this investigation focused on several sites in eastern Missouri, but subsequent activities include all contaminated sites. The Division for Environmental Hazards and Health Effects and the Division of Environmental Health Laboratory Sciences in the Center for Environmental Health of the Centers for Disease Control (CDC) had worked previously with the Missouri Department of Health (MDH) in 1971 (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 reinitiated public health activities on the basis of new information and additional environmental data.

PUBLIC HEALTH ACTIVITIES

The case of dioxin illustrates many of the difficulties encountered in assessing health risks following long-term, low-dose exposure to environmental chemical contaminations.² At the time of our initial investigations, there was no widely available method for directly measuring dioxin levels in human tissue. The lack of any direct measure of body burden or exposure substantially hindered attempts to assess the degree of exposure to and concomitant health risk posed by environmental dioxins. In addition, data on human health effects were limited, thereby necessitating reliance on animal experimental studies and/or cases of accidental acute intoxication in humans. Thus, risk assessment methods were used to estimate risks to potentially exposed human populations to serve as a basis for risk management decisions.³

In doing the exposure assessment calculations for contaminated residential areas in Missouri, we used an iterative simulation model to estimate a 70-yr lifetime dose to an exposed person. Extrapolating doses from chronic feeding studies in rats corresponding to known levels of risk and using cancer as the disease endpoint of concern, we concluded that residential soil TCDD levels of ≥ 1 ppb pose a level of concern for delayed health risks in residential areas. Assuming that an entire area is contaminated at 1 ppb, we estimated the excess lifetime cancer risk to an exposed individual ranges from greater than 1/100,000 to less than 1/100,000,000. This risk estimate would amount to a 0.000023 absolute increase (equivalent to a 0.01% relative increase) over one's "normal" 25-30% lifetime probability of developing cancer in the United States (RR = 25.0023/25 = 1,0001).

Thus, MDH and CDC issues advisories which stated that 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. The U.S. EPA then used these advisories as the basis for risk management decisions.

In addition to ongoing review and assessment of U.S. EPA environmental sampling data, MDH and CDC initiated four distinct public health actions in January 1983:

- Providing health education for both and 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 has enabled 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, if a reliable screening method for TCDD in serum should become available, we will be better able to assess exposure status and concomitant health risks. Baseline and identifying information were collected in

the form of a Health Effects Survey Questionnaire designed to elicit information on possible routes of exposure, life-style habits, residential and occupational histories and medical history. It was also intended to serve as a screening tool for identifying a "highest risk" cohort on whom intensive medical evaluations were focused and in 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.

PILOT EPIDEMIOLOGIC STUDY

In this pilot study,^{*} we assessed potential health effects related to dioxin exposures by three means. First, as previously mentioned, we developed a Health Effects Survey questionnaire to elicit information on each person's exposure risk, medical history and potentially confounding influences. We 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, we sponsored the dermatology screening clinic mentioned above.

Third, we reviewed approximately 800 completed questionnaires and selected 122 persons for inclusion in a pilot medical study. We selected a high-risk group which comprised 82 individuals who reported living or working in TCDD-contaminated areas or participating more than once per week, on the average, in activities that involved close contact with the soil (such as gardening, field/court sports, horseback riding or playing in soil) in 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. We also selected a low-risk comparison group of 40 persons who reportedly had had no access to, or regular high-soil-contact activities in any known contaminated areas. Of the 122 persons selected for study, 104 agreed to participate (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 physical, neurologic, dermatologic, hematologic, immunologic and liver function testing.

The high-risk 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. The only significant difference in lifestyle habits was that the high-risk group reported exercising more regularly (p < 0.01).

We found no differences or consistent trends regarding the prevalence of 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 highrisk 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 from the general community or in the 104 persons in the study groups. In addition, the study population demonstrated no significant differences in all other dermatological findings by either medical history or physical examination.

Results of the neurological examinations showed no significant differences or patterns between the two groups from the selfreported neurological conditions or from the neurological examinations, although a non-statistically significant diminution of vibratory sensation at 256 Hz was noted in the high-risk group.

As reported in the medical histories, there were no differences in prevalence of immune disorders. On physical examination, the only significant difference was a suggestion of a greater prevalence of palpable nodes in the low-risk group. Laboratory analyses showed no statistically significant differences between the two groups, although there was a trend of diminished response to the antigenic skin tests and a greater prevalence of abnormalities in comparisons of parameters from T cell subset assays in the high-risk group.³

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 except for elevated mean urinary heptacarboxylporphyrin in the low-risk group. However, 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 nonstatistically significant higher prevalance of pyuria (>5 WBC/ hpf) and microscopic hematuria (>3 RBC/hpf) in the high-risk group.

The potential health effects considered in this study were based primarily on the animal toxicology of dioxin and results from studies of long-term industrial and accidental acute human exposures. These analyses did not produce any firm indications of increased disease prevalence directly related to the putative exposure. These results did, however, offer some insights and leads for further study. Of interest was the 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 finding of no significant differences in liver function was important; however, it was recommended that hepatic function should be examined in subsequent studies because of other animal and human toxicologic data suggesting hepatotixic effects of TCDD. Although none of the findings from the immune function tests and assays demonstrated statistically significant differences, several results were of note such as a slight increase in relative anergy and an increased prevalence of helper:suppressor T-cell ratios ≤ 1.0 in the high-risk group, although the functional tests of the immune system revealed no overall abnormalities. Further investigation of all of these effects in exposed cohorts was recommended.

EPIDEMIOLOGIC STUDY

We recently completed a more refined epidemiologic study⁴ which was planned to test the results of the pilot study. This medical epidemiologic study of residents of the Quail Run Mobile Home Park in Gray Summit, Missouri, was conducted between

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November 1984 and January 1985 to determine if, and to what extent, the health of individuals who resided in the park for 6 or more months was affected. This population was selected for study because of high levels of dioxin contamination found throughout the environs of the mobile home park, including inside many of the homes. We compared these dioxin-exposed participants with residents from one of three similar mobile home parks that had been tested and found to have no dioxin contamination. At the conclusion of the study, there were 154 exposed and 155 unexposed participants. These persons were evaluated under a protocol similar to that used in the pilot study with the addition of more specific tests of neurobehavioral parameters (World Health Organization's core battery for field studies of persons potentially exposed to neurotoxins), quantitative tests of tactile, vibratory and thermal sensations, and additional laboratory tests (serum IgG and creatinine assays, urine cultures, assay of cytotoxic T-lymphocyte production and liver function tests of microsomal enzyme induction).

The exposed and unexposed groups were comparable with respect to age; sex; race; tobacco and alcohol usage; use of pesticides, wood preservatives or professional herbicidal services; and history of employment that involved contact with chemicals, electrical transformers or capacitors, or the incineration of plastic or wood materials. We also found no difference in the exposed and unexposed subgroups with respect to age and sex. There was, however, a statistically significant difference between the groups for both the mean Hollingshead index score for the head of household (p < .01), which is inversely related to socioeconomic level, and the participants' educational level (p < .01). Educational and socioeconomic levels were lower in the exposed group.

There were no statistically significant differences between the two groups in the number of reports of any diagnosed medical condition except for the categories "other skin problems" and "other miscellaneous diseases." The interview permitted openended responses to these questions, and the participants frequently reported non-physician-diagnosed illnesses. No predominant or statistically significant condition was reported in these categories. No cases of chloracne, acne in nonadolescent years, porphyria cutanea tarda, lymphoma, sarcoma or cancer of the liver were reported. Six persons (2 exposed vs. 4 unexposed) reported having had cancer; one of the exposed individuals had the disease diagnosed more than 20 years before first residing at Quail Run; the other exposed person's cancer was diagnosed l year after the person moved to the park. Although not significantly different, a greater number of the following selected conditions were reported by the exposed group: nephritis (4 vs. 2), cystitis (12 vs. 5), gastric ulcer (5 vs. 2), immune deficiency (2 vs. 0) and depression (7 vs. 6). No statistically significant differences between the two groups were detected for the reported conditions that we could confirm by our review of the medical records. Participants were questioned about their reproductive health since 1971, and no differences were found between the exposed and unexposed groups in the frequency of metrorrhagia, menorrhagia, amenorrhea, infertility, impotence and loss of libido (asked of males only), fetal deaths, spontaneous abortions and children with congenital malformations. For two of 14 symptoms, the prevalence was significantly increased in the exposed group. These symptoms were: (1) numbness or pins and needles in the hands or feet and (2) persistent severe headaches; however, no difference between groups was observed in the proportion of participants who sought medical care because of numbness or headaches.

On physical examination, there was a statistically significant increase in nonspecific dermatitis in the exposed group (16 vs. 2, P <.01), but no cases of chloracne or porphyria cutanea tarda were diagnosed in any individual. Overall, there was no statistically significant difference between the two groups in general appearance, blood pressure, heart rate, magnitude of peripheral pulses, presence of palpable lymph nodes, peripheral neurologic function or proportion with either hepatomegaly or abdominal tenderness.

Routine laboratory tests showed the exposed group to have a statistically significant increased prevalence of elevated white blood cell (WBC) count. Statistically significant differences of other hematologic parameters included mean WBC count, absolute granulocyte count and percentage monocytes in the WBC differential. Categorical comparisons of all parameters of the urinalysis, including microscopic analysis of the urine sediment, showed no differences between the two groups. When analyses were stratified by age group, sex or current menstrual flow in women, we found no differences in regard to these parameters.

In special laboratory tests, the exposed group had an increased prevalence of elevated urinary uroporphyrin levels and a significantly higher mean level of urinary uroporphyrins. In stratified analyses, similar statistically significant differences between groups in mean urinary uroporphyrin levels were found among adults, females, persons reporting no current alcohol consumption and persons with less than a high-school education. No participant had a urinary porphyrin pattern or elevated level of total urinary porphyrins indicative of either latent (> 400 μ g/dl) or overt porphyria cutanea tarda. We found no significant difference between groups means for triglyceride, HDL-C, immunoglobulin G. glucose, albumin, ALT, AST, GGTP, alkaline phosphatase, glutathione-s-transferase, alanine aminopeptidase, beta-glucuronidase and 5'-nucleotidase. The mean values for serum cholesterol, creatinine and bilirubin were statistically different, the value for the unexposed group being higher than that for the exposed group for each of these variables. Multivariate regression analyses using number of years of residence in the park as a surrogate for dose of TCDD showed a statistically significant positive relationship with AST, ALT, GGTP, alanine aminopeptidase and beta-glucuronidase.

Evaluation of delayed-type hypersensitivity skin tests (DTH) revealed significantly decreased responses in exposed participants compared to those who were unexposed. Exposed subjects had a smaller mean number of positive skin tests and decreased average induration than the unexposed group. Subgroup analyses showed that both male and female children had a significantly smaller mean number of positive skin tests. The mean average induration was smaller for exposed children of both sexes, but the difference was statistically significant only for females. For the adult subgroups, the only statistically significant difference was that exposed females reacted to a smaller number of antigens, although both male and female adults tended to have decreased average induration compared with unexposed adults.

A greater percentage of exposed participants were anergic (defined as no positive reactions to any of the seven standard antigens) compared to the unexposed subjects; no children in the unexposed group were anergic. Although the mean induration was significantly less in the exposed group for only two of the seven antigens (streptococcus and Candida), the frequency of nomeasurable-cutaneous-response was significantly greater in the exposed group for all antigens but tuberculin and trichophyton.

In addition to the increased frequency of anergy in the exposed group reported above, a greater percentage of the exposed than the unexposed participants had at least one abnormal immune test or at least two abnormal immune tests. The exposed group had a significantly greater proportion with at least one in vitro immune test abnormality and non-statistically significant increased frequencies of abnormal T-cell subset tests, a T4/T8 ratio <1.0 and an abnormality in the functional T-cell tests.

Specifically, the results of T-cell surface marker analyses showed statistically significant decreased percentages of T3, T4 and T11 cells in the exposed group, but the mean number of each of the T-cell subsets was comparable between groups. Bcell counts were not directly measured, but the number of non-T peripheral lymphocytes was calculated and found to be significantly greater in the exposed group. In vitro T-cell function was assessed by lymphoproliferative responses to three mitogens and tetanus toxoid antigen and CTL activity. Exposed individuals had comparable lymphoproliferative responses to stimulation with phytohemagglutinin, conconavalin A and tetanus toxoid, and they also had a statistically significantly increased response to pokeweed mitogen. The difference in CTL activity between the two groups was not statistically significant.

On the neurobehavioral tests, the mean score for the exposed group was lower (i.e., in the direction of abnormality) than the score for the unexposed group of 7 of 10 of the Wechsler intelligence and memory scales. However, a statistically significant (p < .05) difference between groups in aggregate mean scores was demonstrated for only the vocabulary subtest of WAIS-R by using analysis of covariance.

Statistically significant differences between groups were found in the tension/anxiety and anger/hostility scales of the POMS inventory with higher (i.e., in the direction of abnormality) mean scores in the exposed group. In addition, the mean scores of the exposed group were higher than those of the unexposed group for the depression/dejection and fatigue/inertia scales, although these differences were not significant. There were no statistically significant differences between groups on the Trailmaking A and B, grip strength and simple reaction time tests. The exposed group, however, consistently took longer to complete the tests and made more errors in the Trailmaking tests.

Finally, for the neurosensory tests, we compared the thresholds of the two groups for each digit on both the tactile and thermal sensory tests. There were no differences in mean threshold scores.

The findings from this study suggest that long-term exposure to TCDD may have adverse consequences. TCDD exposure was associated with depressed DTH responses, anergy and in vitro immune abnormalities; however, in view of the absence of significant differences in reports of clinically diagnosed immune suppression and prolonged or repeated infections, the abnormalities found in this study should be considered subclinical. It will be important to follow those individuals who were anergic to determine if their cellular immune function recovers or they develop clinical disease and to study immune function in individuals with known body burdens of TCDD. Similarly, it was recommended that the evidence suggestive of subclinical alterations in liver function among the exposed participants be further investigated. Tests to investigate immune function (delayed type hypersensitivity on in vitro testing) are currently under way.

It is important to keep in mind that those studies were carried out on self-selected populations. There likely were other exposed individuals who declined to participate in these studies. The effect of having a self-selected population isn't known.

ON-GOING STUDIES

Since there is little information on the adverse reproductive outcomes related to long-term environmental exposure to dioxin such as might occur after repeated direct contact with contaminated soils in Missouri, another on-going study is designed to provide information to determine if such exposure increased the incidence of malformations, fetal deaths, low-birth-weight babies and infant mortality. The exposed group will consist of all babies born between January 1, 1972 and December 31, 1982, for whom the residence address of the mother is close to documented areas of dioxin contamination; there are approximately 400 such babies. The outcome data (based on a review of medical records of newborns) for this group will be compared to data for approximately 800 babies born near in time at the same hospital as the exposed babies to mothers whose race is the same and whose age is within 5 years of the exposed mothers' ages. In addition, a survey of all hospitals in the state for malformations diagnosed in infants by the age of 1 year will be conducted in order to provide information for baseline reference and for updating the medical records review of exposed and matched unexposed babies. The study began in July 1985 and is expected to be completed by late 1986.

Research into characterizing TCDD body burden measurements was designed to study dioxin levels in adipose tissue and serum from persons exposed to dioxin at residential and commercial sites in Missouri. Volunteers underwent excision of 20 g of adipose tissue by a plastic surgeon working on contract for the Missouri Department of Health. Tissue specimens also were obtained from volunteers who had no known exposure to dioxin. These specimens from "unexposed" persons will comprise a matrix based on age, sex, race and residence location. Testing of specimens from the first 97 persons tested (39 exposed and 58 unexposed) are under way. Measurement of TCDD in adipose provides a much improved measure of exposure which is important for studies evaluating the possible health effects of this compound.

A study currently is underway in Missouri to collect blood from persons who have donated adipose samples for the purpose of developing a serum test of 2, 3, 7, 8-TCDD. If such a test can be developed, then a surgical procedure will no longer be needed to determine exposure to 2, 3, 7, 8-TCDD. With such a test, it also will be possible to carry out studies to determine the half-life of 2, 3, 7, 8-TCDD in man. A drawback to the serum test is that the current laboratory method requires 200 to 250 ml of serum.

We also are conducting medical tests on persons who think they have been exposed to 2, 3, 7, 8-TCDD to see if they have immunologic or other abnormalities.

Finally, CDC, the state Departments of Health and other agencies (such as the Agency for Toxic Substances and Disease Registry) will continue to review environmental data from dioxin-contaminated sites in Missouri to establish or update health advisories. Furthermore, all involved public health agencies will continue to provide health education about dioxin exposure to the medical community and the general public.

CONCLUSIONS

In conclusion, collaborative studies between the Missouri Department of Health and the Centers for Disease Control (funded by the U.S. EPA and the Agency for Toxic Substances and Disease Registry) have been carried out for the past 4 years. Tests have been developed which show that a variety of persons have been exposed to 2, 3, 7, 8-TCDD in recreational, residential or occupational settings. Some immunologic and liver abnormalities have been identified in persons with 2, 3, 7, 8-TCDD exposure. It is unclear whether these abnormalities are markers of exposure, biochemical effects or precursors to future disease. Now that we can measure 2, 3, 7, 8-TCDD in the adipose tissue of persons, we can determine objectively which persons actually have been exposed to 2, 3, 7, 8-TCDD.

Research in these areas will continue in order to develop a more complete understanding of the risks and appropriate public health interventions in situations of community exposure to environmental dioxins. However, public health policy must continue to be focused on the prevention of potential health effects, even if such effects are not yet fully understood. For this reason, all appropriate efforts need to be made to prevent human exposure.

Table 1 Major Milestones in the History of Dioxin in Missouri

1971

- Roads, arenas, parking lots sprayed with waste oils throughout Missouri
- Deaths of rodents, birds, horses in three Missouri horseback riding arenas
- · Child presents with hemorrhagic cystitis
- Epidemiologic investigation implicated oil spraying but specific agent could not be identified

1974

- Oil residue analyzed, 2,3,7,8-TCDD identified at levels of 33,000 ppb in riding arena
- Recommendations to clean up the sites is tempered by the belief that environmental half-life is 6 months

1982

- Resampling at known contaminated sites shows 2,3,7,8-TCDD to be still present
- EPA and Missouri DNR initiate extensive evaluation of approximately 250 sites
- CDC and Missouri Department of Health reinitiate health investigation
- Times Beach is evacuated after extensive contamination is found in soil

1983

- Pilot study
- Central Listing set up
- Chloracne screening clinic
- · Follow-up epidemiologic study recommended

1984

• Quail Run Study begun

1985

- Study finished
- Quail Run Study finished
 Missouri Adipose Study begun
- Reproductive Outcome Study begun
 - 1986

- Quail Run Study results published
 Follow-up of Quail Run Study participants with immunologic abnormalities carried out
- Initial results of Adipose Study released

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A National Study of Site Discovery Methods

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ABSTRACT

Under contract to the U.S. EPA, Booz, Allen & Hamilton Inc. conducted a national study of methods for discovering potential hazardous waste sites. The study was conducted by interviewing U.S. EPA staff in Headquarters and in Regional offices, selected staff of States that have a range of site discovery programs, and firms under government contract that have site discovery responsibility.

Our findings indicate a large variety of possible site discovery mechanisms. Further, a large number of industries that are potential site producers are identified. A preliminary analysis was carried out to subjectively compare financial, capture efficiency and administrative elements of site discovery mechanisms. The results of the analysis can be used to direct effective approaches to site discovery.

INTRODUCTION

Interest in conducting a study of site discovery program needs has arisen because of congressional inquiry, proposed Superfund reauthorization language and a Mar. 26, 1985, General Accounting Office report, titled, "EPA's Inventory of Potential Hazardous Waste Sites is Incomplete."

Discovery and identification of releases or threatened releases of hazardous wastes have been reported to the U.S. EPA through the 103(c) program and a large variety of other mechanisms across the country. These include: State government investigation; selected facility inventories; random Federal, State and local government agency observation: informal private observation; and reporting of present hazardous waste operations under RCRA. These methods are presently part of the discovery program.

The exact magnitude of the uncontrolled hazardous waste problem on a national level remains unknown. This uncertainty may result in inaccurate determinations of the amount of resources ultimately needed to understand and remedy the problem. Analysis of current discovery methods could result in program changes that will better forecast future U.S. EPA, State or private resources and schedules to meet Superfund's comprehensive objectives.

The overall objectives of this phase of the project were to:

- Develop an understanding of the current status of nationwide site discovery activities
- Prepare conceptual options and determine requirements for a proactive nationwide site discovery program

This paper is organized in four sections. First, a discussion of the approach for the study is presented. Second, the study findings are summarized and discussed. Third, a comparison of the various site discovery mechanisms using financial, capture efficiency and administrative criteria to understand the relative advantages of various site discovery mechanisms is made. Finally, some conclusions are made and particular areas of importance are noted.

APPROACH

Site discovery program information was collected by two methods: telephone inquiries and personal interviews. The telephone inquiry was conducted in order to understand current approaches to discovery activities throughout the country and to identify specific discovery mechanisms. Regional U.S. EPA staff and State personnel with CERCLA responsibility were interviewed.

An interview guide was used during the telephone inquiries. The first questions provided an understanding of Regional or State goals in site discovery and the status of current programs. Additional questions were asked about the types of industries present in the State usually associated with the existence of hazardous waste sites. The remaining questions addressed the need for prescreening site information by the States, the existence and status of a State data base and the compatibility of the data base with CERCLA Information System (CERCLIS). Prescreening is a term used for any cursory analysis of sites by a State to determine whether or not a site will be entered into CERCLIS.

At least one person from each U.S. EPA Regional office was interviewed. Further, staff from 40 different State agencies were interviewed; about 80% of the States in each Region were contacted. Both U.S. EPA Regional and State staff were asked to provide information on their contractors' activities related to site discovery.

The second method used for collecting information consisted of developing a more in-depth understanding of site discovery activities through in-person interviews. Region V and its constituent States were selected for these interviews because of the large number and diversity of sites within the Region. Questions similar to those in the telephone interviews were asked. In addition, group discussion among the participants allowed opinions and attitudes toward a potential site discovery program to be discussed in more detail and at greater length than in a telephone interview.

FINDINGS

Information gathered during the telephone and in-person interviews is presented in this section. A synthesis of this information serves to detail current site discovery activities and identifies industries of actual and potential CERCLIS concerns. Highlighted in our findings are administrative, legislative and technical aspects of site discovery activities. Included are summaries of:

- Site discovery-related characteristics of state wide programs
- Site discovery mechanisms

• Industries or activities likely to result in hazardous waste sites

Figure 1 presents site discovery-related characteristics of State programs for States participating in the study. The darker part of each pie chart indicates the percent of affirmative responses to the interview questions. For example, 40% (16 out of 40) of the States interviewed had proactive site discovery elements in their CERCLA programs; these 16 States were evenly distributed throughout the country; thus, the existence of a proactive program did not seem to be influenced by geographic location.



Site Discovery Related Characteristics of State Programs

Fifteen of the 40 States interviewed had hazardous waste site data bases. Eight of these States had their own "Superfund-type" legislation which provided impetus for site discovery activities. Only one State with the legislation did not mention having a data base in the interview. A hazardous waste site data base was found in seven States with no local legislation. Except for Region V (greater than average affirmative answers) and Region IV (fewer than average affirmative answers), the States with data bases seemed to be evenly distributed among the Regions.

The criteria used for entry of sites into each State data base varied greatly. The information contained in existing data bases was found to be inconsistent. It varied in type and description of sites included. In addition, the level of effort used to create and maintain the data base was different, which resulted in different depths of coverage of potential sites.

Only two States with a data base have systems compatible (i.e. containing information about the same sites) with the CERCLIS data base. State data bases may have sites that could have been included in the CERCLIS data base as well as sites not included in the Superfund definition of a hazardous site. For example, they might include sand and gravel operations, salt water intrusion sites, sites containing petroleum and other substances excluded from Superfund. They also may have omitted sites included in CERCLIS. In the former case, better use of existing information

SITE DISCOVERY MECHANISM



Figure 2 Frequency of Site Discovery Mechanisms Utilized by States

could prove to be a method of "discovering" new sites for both States and CERCLIS.

Initial program guidance in the area of site prescreening can be found in the 103(c) notification. Forty percent (16 of 40) of the States surveyed perform a prescreening test to some degree before the data are entered into CERCLIS. Prescreening criteria are selected by each State according to its own needs and priorities. The U.S. EPA neither reviews nor approves the prescreening activities of individual States.

Prescreening of potential sites has several implications for the Superfund process. Prescreening by States can reduce the number of ineligible sites that are reported to CERCLIS and decrease costs associated with further pre-remedial investigation. Conversely, if State prescreening criteria are not in agreement with Superfund requirements, some sites may be prematurely disqualified, thereby increasing future Superfund costs.

Figure 2 presents a summary of site discovery mechanisms which emphasizes the variety of ways in which sites presently are discovered by the States. Because the data used to prepare this figure were collected through one or two interviews per State, it is likely that the frequency of each mechanism used was underestimated. For example, States that mentioned only one or two mechanisms may, in fact, utilize more. Other possible mechanisms such as some types of historical searches (trade association information, the telephone directory, trade journals, etc.) were not mentioned at all.

Citizen complaints, site identification through Preliminary Assessment/Site Inspection (PA/SI) work, referrals by State agencies and other, unrelated types of inspections were some of the most frequently mentioned mechanisms. These methods are classified as passive since they do not require Regions or States to make a concerted, organized effort to obtain the information. The information is volunteered or funneled through various channels until it comes to the attention of the U.S. EPA. On the other hand, active mechanisms are those in which purposeful actions are undertaken to obtain new sites. Examples of these are historical searches, solicitation of State agencies and special projects such as an industry-based survey.

The aforementioned passive mechanisms were reported most frequently for several reasons: they can function with a limited Site Discovery Program; they are low cost and require no capital or overhead expenses. Some active mechanisms function at present in several States. However, usually only those States with Superfund type legislation and local data bases are likely to know about and/or use active mechanisms.

COMPARISON OF SITE DISCOVERY MECHANISMS

A preliminary analysis was made to subjectively compare the relative advantages and disadvantages of implementing the site discovery mechanisms suggested by the telephone interviews. The analysis compared financial, capture efficiency and administrative elements of the site discovery mechanisms.

In Table 3, a matrix of selected site discovery mechanisms versus critical elements was used. Numbers ranging from -2 to +2 were assigned to the variables to indicate their relative desirability (from least to most desirable, respectively). Comparing the totals of the horizontal rows allowed the mechanisms to be ranked according to their relative desirability.

Table 1						
Relative Desirability of Selected Site Discovery						
Mechanisms by Numeric Values						

N		INANC	IAL	1	APTUR	E EFFI	CIENCY	<u> </u>	ADMI	HISTR/	TIVE		
CRITECAL ELEMENTS FOR EPA BITE DISCOVERY WECHANISH	Frank End Costs	Chreat Costs	Indexe Costs (to other endine)	Start	1	Total Number Of San	Total Time Utilized	Edward Contracts Residences	Rent Control		Number of Case	Numeral Constants	TOTAL
PAGGIVE				<u> </u>	·	r	r		r	-		. -	
	⊢.			<u> </u>	<u> </u>			<u> </u>	<u> </u>	\vdash		<u> </u>	
Calizan Complaint	-		•	-	<u> "</u>	<u>'</u>	-		<u> </u>		-	-	<u>`</u>
-PA/SI By-product	,	*	<u>'</u>	1		<u> </u>	<u> </u>	2	<u>'</u>	<u>'</u>	<u>∣</u> •	-1	11
-Property Transfer Regs.	1	2	<u>'</u>	2		1			,	- '	-1	-1	•
				ļ	I						L		
other agency	2	2	,	2	1.1	-1	2	2	-	1		14	
branch	2	2	1	2	-1	0		1	<u>'</u>	-1	•	-1	
other inspections	2	2	1	2	-1	٥	2	2	1	-1	•	-1	•
-Responsible Party Report	2	2	2	2	2	-1	2	2	•	-1	4	-1	•
-5pBs	2	2	2	2	-1	4	1	2	1	1	-2	-1	7
ACTIVE											Г <u> </u>		
-EPIC Review	-1	-1	•	`	,	١	•	-1	4	1	,	•	1
Helpicel Beart/Fla Review	-1	-1	1	1	2	2	4	-1	-1	-1	,	•	•
-PA/SI By-product	1	0	-1	-	0	2	•	4	-1	-1	1	,	3
-Referation													
-other agency	ŧ	0	-1	3	.1	0	1	•	•	-1	-1	1	•
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-other inspections	1	0	-1	2	1	1	1	ł	٥	-1	1	1	7
-Responsible Party Bearch	-1	-1	1	-1	0	,	1	-1	1	,	0	-1	4
-Solicitation	-1	0	1	1	1	1	0	0	-1	-1		1	•
SPECIAL STUDIES													
-Geographic Area	.3	.7	1	+	2	2	-1	4	-1	1	8	1	3
industry while	-2	-2	1	1	1	1	4	-1	-1	2	3	2	4
Policiani	4	4	1	4	-1	-1	-1	•1	-1	ł	8	8	4
LEGEND -2 0	M	2 Ioni Den	irabie							-			

In this approach, a weighting factor could be used to allow any specific mechanisms or critical elements to be given more or less relative importance. By using this process, selected elements that may strongly influence site discovery mechanism selection could be taken into account. For example, cost may be considered to have a greater negative impact than other elements in decisionmaking, therefore it would be multiplied by a factor greater than that of the other elements.

For decision-making purposes, the comparison of various versions of the analysis, with the application of different weighting factors or different combinations of the weighting factors applied to the mechanisms or elements, would aid in the selection of mechanisms for a site discovery program. For purposes of this report, no weighting factor was used for any mechanism or critical element.

For this analysis, site discovery mechanisms were put into three groups: passive, active and special studies. Passive mechanisms are defined as actions that occur with minimal organized efforts by the U.S. EPA or States doing Superfund work. In this group, EPA primarily receives unsolicited information from sources external to CERCLA such as interested private parties, referrals or as a result of activities under other laws and regulations. Only where additional sites were discovered as PA/SI by-products would the U.S. EPA and the States' CERCLA programs be directly involved in producing the information.

Active mechanisms are those that involve planning and direct costs to the U.S. EPA and the States. Since referrals, PA/SI byproducts and responsible party reporting are mechanisms that may be passively or actively encouraged, they are included in both the active and passive groups.

Special studies, such as geographic area or industry-specific studies, are highly organized efforts with well defined objectives, methods and timeframes. They may be instituted on a national, regional or local scale.

The critical elements used to compare the mechanisms are also divided into three categories: financial, capture efficiency or administrative. The first two elements may be defined subjectively or mathematically; the third is very difficult to rigorously define. The financial elements are the various monetary costs associated with the mechanisms. Capture efficiency elements are those related

Table 2

Preliminary Ranking of Site Discovery Mechanisms By Financial, Capture Efficiency, and Administrative Critical Element

RUNKING OF CATTCAL ELEMENTS SITE DISCOVERY MECHANISM	Overali Ranking *	Financial Ranking	Capture Efficiency Ranking	Administrative Rantiding
1 Relemais: Other inspections **	1	3	3	3
2. Property Transfer Regulations	1	2	•	•
3. Referrals: Other EPA Branch**	1	3	1	د د
4. PA/SI By-product **	2	3	2	•
6. Spile	2	1	6	•
8. Referrals: Other Agency **	3	3	3	5
7. Cilizen Complaint	٩	•	٩	2
8. Solicitation	5	3	3	•
9. Industry-wide Study	5	7	1	1
10. Geographic Area	6	,	3	1
11. Responsible Party Report **	7	1	s	•
12. Historical Search/File Review	•	6	3	
13. Remote Sensing Review	,	•	•	•
14. Pollutant Study	10	7	,	1

** These sumbers are the average scores from active and passive elements of this mechanism

to the end result of mechanism utilization. The last category, administrative elements, indicates the relative difficulty in implementing each mechanism from a management and institutional standpoint.

The results of the model, although qualitative, can be used to formulate initial positions on the relative desirability of implementing selected mechanisms and as a focus of discussion for the evaluation of specific critical elements related to the mechanisms. Although the information presented in Figure 4 is preliminary, it is included to present its potential application to site discovery decision analysis.

Ordering these totals from highest (1) to lowest (10) rank gives the most to least desirable site discovery mechanism. Table 4 presents the ranking of site discovery mechanisms. The first column is the overall ranking, based on the summation of all the factors composing the critical elements. It is not based on a summary of the other rankings. The mechanisms are listed according to the overall ranking from most to least desirable. The results vary according to the critical element used to rank. This division of decision criteria allows a separate evaluation of each element. In future iterations, it would be simple to revise the factors included in each element or add relative weightings to them.

CONCLUSIONS

In this report, information was presented about background characteristics of State programs related to site discovery, mechanisms for discovery utilized by the States and industrial types that are potential sources of hazardous waste sites. One type of decision analysis that compares site discovery mechanisms to financial, capture efficiency and administrative elements provided a preliminary ranking.

The findings suggest that passive mechanisms (with the exception of responsible party reports) are the most desirable because they cost less than active mechanisms, produce positive results and function with or without a formal program. These mechanisms can be formalized through development of guidance at a relatively low cost.

Studies, especially of a selected industry, should be given further consideration as a potential method of discovering new sites because of its high capture efficiency and administrative rankings.

The Difficulties of Modeling Contaminant Transport At Abandoned Landfill Sites

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ABSTRACT

The role of contaminant transport models in remedial investigations and feasibility studies for hazardous waste sites is to assist in formulating appropriate questions concerning the remedial planning and design activities for the site and to help obtain quantitative answers of sufficient accuracy and detail to guide remedial action at the site. The problem of developing a contaminant transport model which can produce quantitative answers of sufficient accuracy and detail usually is difficult due to the lack of information about the contaminant transport properties of the subsurface environment as well as the attenuation properties of the contaminants. This problem becomes even more difficult when trying to simulate contaminant movement at abandoned landfill sites. Not only is information about the above properties scarce, but also little or no information often is available about the amounts of contaminants released into the environment and/or when they were released.

The most useful models are those that have been calibrated and verified. Traditionally, calibration of a contaminant transport model involves comparing concentrations of contaminants measured in the field to those predicted by the model for a given historical spill or release event and then adjusting the contaminant transport parameter values so that model results more closely reproduce the measured concentrations. Calibration thus requires a reasonable estimate of the contaminant loading rate(s) for each source at the site. Unfortunately, at abandoned landfill sites, there usually are not enough data to make a reasonable estimate of past, present or future contaminant loading rates. There are few records, if any, indicating what and how much waste was deposited at the site, let alone when and at what rate contaminants were released into the environment. When historical data are not available, it sometimes is possible to estimate average contaminant loading rates based on the contaminant plume concentrations measured in the field. It is imperative, however, that the contaminant plume be well defined in these cases.

The inability to calibrate a contaminant transport model does not make contaminant transport modeling useless in abandoned landfill site investigations. Although calibrated models are more useful than uncalibrated models, certain measures can be taken to obtain useful information from uncalibrated models. Ranges of values for the contaminant transport parameters can be estimated based on previous modeling studies and research. Model results for given scenarios then can be investigated over those ranges of values. In this capacity, the model can be used to predict ranges of contaminant migration. The results then may be used to increase understanding of the contamination problem and thus help guide the risk assessment and decision-making process for remedial action at the abandoned landfill site.

INTRODUCTION

The use of contaminant transport models in hazardous waste site investigations is becoming more common. More investigators are discovering how useful these models can be in guiding remedial action at hazardous waste sites where groundwater has been contaminated. In addition, more groundwater professionals are becoming proficient in their use, thus increasing the number and percentage of successful model applications. With this increase in model use comes an increase in understanding the contaminant transport processes in groundwater systems as well as an increase in knowing how to apply these models at various sites. Like any other discipline, the groundwater profession learns from its accomplishments and its mistakes.

The purpose of this paper is to relay some of the author's knowledge and experience to the groundwater profession by discussing some of the difficulties of modeling contaminant transport, particularly at abandoned landfill sites. Before anyone can understand these difficulties, however, one must first understand the roles of contaminant transport models in hazardous waste site investigations as well as the process or approach taken to develop a useful model. The first two sections of this paper are thus devoted to these topics.

THE ROLE OF CONTAMINANT TRANSPORT MODELS

The role of contaminant transport models in remedial investigations and feasibility studies for hazardous waste sites is to help formulate appropriate questions concerning the remedial planning and design activities for the site and to help obtain sufficiently accurate and detailed quantitative answers to guide remedial action at the site. The role of these models is not to provide precise answers to the questions posed but rather to produce results which will guide the decision-making process. Contaminant transport models are tools that can aid the study of groundwater contamination problems and can help increase understanding of the groundwater system. Just as an X-ray machine is a tool which helps doctors examine the internal parts of the human body, a contaminant transport model is a tool which helps scientists and engineers evaluate the internal constituents of the groundwater system. Both enable the professional to evaluate the problem without actually having to see it, and both provide results which require interpretation by a professional who understands the tool's limitations. Unfortunately, for the groundwater professional, contaminant transport models have many more limitations than X-ray machines, some of which are discussed in this paper. In spite of the limitations, however, contaminant transport models, when developed and used properly, do provide the most technically sound results on which decisions regarding groundwater remediation can be based. Contaminant transport models thus eliminate the necessity to base groundwater remediation decisions solely on intuition and past experience.

Contaminant transport models can perform three valuable functions when investigating a groundwater contamination problem: organized representation, knowledge amplification and comparative evaluation. These three functions are discussed below.

Organized Representation

One of the major problems encountered in remedial planning or design for many hazardous waste sites is to represent and display in simple and consistent terms the numerous characteristics of the groundwater system. The hydrogeologic data collected for most sites are marginally useful in their raw form and need to be organized in some fashion to provide a simple but complete picture of the system. Contaminant transport models provide a means for the representation of such systems, whether simple or complex, and for actually carrying out much of the computation required for this organization.

Knowledge Amplification

When properly developed and used, contaminant transport models can amplify available knowledge of the behavior of a groundwater system. Contaminant transport models do not produce new data but do permit the extraction of greater amounts of information from the existing data base. They can be used to simulate past or present conditions, or they can be used to predict future conditions. In this sense, contaminant transport models increase the understanding of the problem and of the possible solutions.

Comparative Evaluation

Contaminant transport models can be developed to produce measures of performance of the groundwater system in response to different stresses or actions. These measures of performance then can be used in the comparative evaluation of the various actions. For instance, at most hazardous waste sites, the future contaminant attenuation and migration patterns under several remedial action alternatives need to be evaluated. These remedial action alternatives may include:

- Natural flushing/no action
- Accelerated flushing using additional recharge
- Source removal such as excavation
- Plume containment by hydraulic measures such as pumping
- Plume containment by physical measures such as slurry walls
- Plume extraction using pumping

Contaminant transport models can project or predict the consequences of these actions in terms of time and effectiveness. These predictions then can be used as a basis for comparing the remedial action alternatives. Of course, other factors such as cost and implementability should be considered, too, before selection of the "best" remedial alternative is made for the site.

Contaminant transport models represent the behavior and performance of the complex real world aquifer system and therefore are very powerful analytical tools. Because of their usefulness, they play a very important role in remedial investigation and feasibility studies for hazardous waste sites. However, they, like most models, are an approximation of the real world system and are not completely equivalent to the real world in all aspects. The worst possible misuse of a contaminant transport model is blind faith in model results.

MODELING APPROACH

The development of a contaminant transport model for a hazardous waste site investigation involves several areas of effort. These areas are outlined in the flow diagram shown in Fig. 1 and include: system conceptualization, data collection, solution technique selection, data preparation, calibration, verification and prediction. These tasks should not be considered separate steps of a chronological procedure but instead should be considered as an iterative procedure where each step results in feedback of how the "new knowledge" obtained fits with what was previously known about the site. Often, changes in the modeling technique or the level of detail are necessary as model development proceeds. For this reason, a clear objective of the study is required before the study can begin.

System Conceptualization

Development begins with a conceptual understanding of the physical system. Since simulation of a groundwater system refers to the development and operation of a model whose behavior assumes the appearance of or approximates the actual system's behavior, it is imperative that the modeler have at least a basic understanding of the physical behavior of the actual system. The general cause-effect relationships must be identified. For groundwater flow, these relationships usually are known and are expressed in terms of hydraulic gradient and flow directions. For the movement of contaminants, these relationships usually are only partially understood but are expressed in terms of plume attenuation or migration.



Figure 1 Modeling Approach

Data Collection

All available hydrogeologic and analytic data need to be compiled, reviewed and assimilated for the site. These data include but are not limited to:

- Boring logs which identify the various geologic formations
- Aquifer performance, slug, tracer, and laboratory test results which are used to determine aquifer properties
- Climatic data such as rainfall and evaporation rates
- Water level measurements
- Water quality measurements
- Streamflow measurements
- Contaminant source characteristics such as mass loading rates into the aquifer system

The amount of data needed depends on the complexity of the site, the level of detail required and the desired reliability of model results. An extensive field program, normally included as part of a remedial investigation, may be needed to collect all the necessary data. At many sites, however, important data may be too costly or even impossible to collect. In these cases, the data gaps have to be filled with assumed values. These assumptions directly affect the reliability of the model results. The reliability of the results also is influenced by the quality of the data collected. Modelers must, therefore, never overlook the data collection step as being trivial, for insufficient or bad data will limit the usefulness of their models. The old adage "garbage in, garbage out" is all too possible in contaminant transport modeling.

Solution Technique Selection

A wide variety of solution techniques presently are being used by groundwater professionals to solve contaminant transport problems. These techniques range from simple one-dimensional analytical solutions to complex three-dimensional numerical solutions. Physical and electrical analog models have been used in the past, but today these types of models generally are considered archaic. The choice of the solution technique depends on several factors: the objective of the study, the complexity of the site, the amount of data and the desired reliability of model results. The choice of the solution technique should be left to the experienced modeler who knows the advantages, disadvantages and limitations of each technique.

Data Preparation

Data preparation for contaminant transport models first involves determining the physical and artificial boundaries of the region to be modeled. Physical boundaries are those that actually take shape in the form of some hydrogeologic feature and for all practical purposes will not move. Examples of physical boundaries are impervious geologic formations such as bedrock (no flow boundary) and constant head sources or sinks such as rivers or springs (constant head boundary). Artificial boundaries are those that occur in the environment under a certain set of conditions but which move or change if the conditions change. For obvious reasons, artificial boundaries need to be set far enough from the site so that any conditions imposed at the site will not significantly impact the boundary. An example of an artificial boundary is a groundwater divide (no flow boundary).

Once the boundaries have been defined, a coordinate system must be set up. For numerical models, the region must be subdivided into a grid system. Depending on the numerical procedure, the grid may have rectangular or polygonal shaped subdivisions. For three-dimensional models, the vertical dimensions also must be subdivided. This step generally involves defining the elevations of each hydrogeologic unit across the model area.

After the coordinate system or grid system has been laid out, values for the aquifer properties and stresses as well as contam-

inant attenuation properties are specified. For numerical models, values must be assigned to each subdivision. For most practical problems, aquifer properties, aquifer stresses and chemical attenuation properties include:

- Horizontal and vertical hydraulic conductivities
- Storage coefficients or specific yields
- Effective porosities
- Longitudinal and transverse dispersivities
- Retardation factors
- Biological/chemical decay rates
- Pumping rates
- Rainfall recharge
- Contaminant source loading rates

The last step in preparing data for the contaminant transport model is specifying the initial conditions. Starting water level elevations and contaminant concentrations are needed to begin modeling.

Calibration

Before a contaminant transport model is used as a predictive tool, it should be calibrated to the best extent possible with presently available data. The most useful models are those that have been calibrated and subsequently verified. The procedure for calibration involves selecting past inventory periods where data are sufficient to investigate the distribution of model parameters. Usually, calibration of contaminant transport models is divided into two phases: groundwater flow calibration and contaminant transport calibration. Before a contaminant transport model can be expected to adequately simulate groundwater movement.

Groundwater flow calibration usually involves comparing model-generated aquifer water levels to observed aquifer water levels and performing a sequence of adjustments in the flow parameter values so that modeled water levels more closely reproduce observed water levels. Since there are numerous combinations of hydrogeologic parameters that can yield similar aquifer responses, the ranges of parameters used to match historic data are kept within realistic limits. Parameters that are considered to be least reliable usually are modified more than other parameters. The primary concern of this process is the global response of modeled water levels in both space and time. Although small areas within the model may not match historical data for every different hydrologic condition imposed, systematic mismatches are investigated and eliminated.

Traditionally, calibration of contaminant transpolrt involves comparing concentrations of contaminants measured in the field to those predicted by the model for a given historical spill or release and then adjusting the contaminant transport parameter values so that model results more closely reproduce the measured concentrations. The contaminant transport calibration procedure is very similar to calibration of groundwater flow. Calibration of contaminant transport, however, requires that reasonable estimates of the contaminant loading rate(s) and duration(s) be made for each source at the site.

No hard and fast rules exist to indicate when a contaminant transport model is calibrated. The number of test simulations re quired to produce a satisfactory match of observed readings depends on the objectives of the study and the complexity of the site. The point at which a contaminant transport model is considered to be calibrated is usually left to the judgment of the groundwater professional.

Verification

The verification process generally is performed to provide additional assurance that the contaminant transport model is an adequate representation of the hydrogeologic system. The process basically consists of using historical data from time periods other than the calibration time periods as input to the calibrated model to simulate the associated historical responses. Unfortunately, at hazardous waste sites, data are usually so scarce that the verification process is bypassed. Verification of the groundwater flow parameters sometimes is possible, but rarely, if ever, is verification of the contaminant transport parameters possible.

Prediction

The main purpose of prediction for hazardous waste site investigations is to estimate the rates and directions of contaminant movement under various conditions imposed. The fate of the contaminants if no action is taken is always an interesting prediction. How long it will take to remove the contaminants under different extraction well schemes is also an interesting prediction. Generally, the prediction step is used to determine what, if any, remedial action should be taken at the site.

ABANDONED LANDFILL MODELS

As can be seen in the previous section, developing a useful contaminant transport model can be a long, tedious and often difficult task for any type of hazardous waste site. The amount of data required to develop a contaminant transport model which can produce quantitative answers of sufficient accuracy and detail usually is quite extensive. At many hazardous waste sites, not all the necessary data are available. This makes calibration very difficult. Among the more difficult sites to model are abandoned landfill sites.

At most hazardous waste sites, enough information usually is available or can be easily obtained to adequately develop and calibrate the groundwater flow portion of a contaminant transport model. One exception may be a site where groundwater flows through fractured or cavernous media. Flow in fractured or cavernous media is an area for which models are not yet well developed. Groundwater flow in porous media, however, usually can be modeled without much difficulty. Thus, the difficulties of modeling contaminant transport at most hazardous waste sites usually do not arise from a lack of information about the flow properties of the aquifer system but instead stem from a lack of information about the contaminant transport properties of the aquifer system as well as the attenuation properties of the contaminants themselves.

The properties in question include:

- Longitudinal and transverse dispersivities
- Retardation factors
- Biological decay rates
- Chemical decay rates

The meanings or definitions of these properties are not important to this discussion, and since there are many other references which explain them quite adequately, they are not discussed. Contaminant transport is a growing science, and values for the above properties are not easily measured or determined. Therefore, these properties usually are considered calibration properties and initial estimates are obtained from other studies at similar sites. A great deal of uncertainty emerges, however, when dealing with so many unknown parameters. Because of this uncertainty, calibration is very difficult and generally is performed on an order of magnitude basis.

The above difficulties in developing a contaminant transport model are common to all sites. Abandoned landfill sites, however, have a characteristic which makes contaminant transport modeling even more difficult. This characteristic may not be unique, but it is common to most abandoned landfill sites. Not only is information about the contaminant transport properties

of the aquifer system and the contaminant attenuation properties scarce, but also many times little or no information is available about the amounts of contaminants released into the environment and/or when they were released. As was stated previously, calibration of a contaminant transport model requires reasonable estimates of the contaminant loading rates for each source at the site. In any model study where the properties of the system are not well defined, simulation of a particular response and calibration of these properties require that the stress which created this response be known. Otherwise, there are too many unknowns for the model to be calibrated. Therein lies the root of the problem for modeling contaminant transport at abandoned landfill sites. In this case, the contaminant concentrations in the groundwater system are the response and the contaminant loading rates are the stress. Unfortunately, there usually are not enough data to make a reasonable estimate of the past, present or future stress.

While it is true that there are few, if any, records indicating what and how much waste was deposited at an abandoned landfill site, let alone when it was released into the environment, it sometimes is possible to estimate average contaminant loading rates based on the contaminant plume concentrations measured in the field. The total mass of contaminants released into the aquifer system can be estimated from the concentrations measured (allowing for loss due to attenuation). The total time of release can be estimated by dividing the length of the plume (allowing for dispersion and attenuation) by the average linear flow velocity. From these two estimates, a crude average historical loading rate can be calculated. Even for a crude estimate, however, it is imperative that the contaminant plume be well defined in terms of the areal and vertical variation in concentration of contaminants.

Because of the many difficulties inherent in calibrating a contaminant transport model for an abandoned landfill site, calibration often is not possible. The inability to calibrate a contaminant transport model, however, does not make contaminant transport modeling useless. Although calibrated models are more useful than uncalibrated models, certain measures can be taken to obtain useful information from uncalibrated models.

Ranges of values for the contaminant transport parameters can be estimated based on other modeling studies and research. Ranges of contaminant loading rates can be estimated based on the little information that does exist for the site. If a thorough analysis is desired, the model results for given scenarios then can be investigated over all value ranges. In this capacity, the model can be used to predict ranges of contaminant migration and concentration at key points.

If only a conservative approach is desired for the study, the number of simulations can be reduced significantly by only investigating model results for the worst case conditions of parameter values. In this capacity, the model can be used to predict the worst possible extent of contaminant migration and the worst possible concentrations of contaminants at key points.

Thus, although an uncalibrated contaminant transport model cannot indicate or predict with any reasonable degree of reliability the actual fate of contaminants in the groundwater system, it can predict with a good degree of reliability what can and cannot happen to these contaminants. These results then may be used to increase our understanding of the contamination problem and thus help guide the risk assessment and decision-making process for remedial action at the abandoned landfill site.

CONCLUSIONS

Contaminant transport models are important tools in hazardous waste site investigations. They can be used to simulate the movement of contaminants in the groundwater system under many different conditions and thus help guide the decision-making process for remedial action at these sites. The development of these models involves conceptualizing the system, collecting data, selecting a solution technique, preparing the data, calibrating the model, verifying the model and finally making the predictions. Because of the amount of information needed to perform these tasks, development of a contaminant transport model is usually a long, tedious and often difficult task.

Among the most difficult sites to model are abandoned landfill sites. While most hazardous waste sites are difficult to model due to the lack of information about the contaminant transport properties of the aquifer system and the attenuation properties of the contaminants themselves, abandoned landfill sites have an added complication; many times there is little or no information available about the contaminant source characteristics. Without reasonable estimates of contaminant source loading rates, the contaminant transport model cannot be calibrated. An uncalibrated model, however, is not useless. An uncalibrated model can be used to predict ranges of contaminant migration based on estimated ranges of contaminant transport parameter values. These results will help to increase our understanding of the contamination problem which otherwise might have been lacking.

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Town Gas Plants—History, Problems And Approaches to Study

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ABSTRACT

Town gas plant sites are receiving increasing attention from the utility industry and regulatory communities. This attention has been prompted by greater environmental awareness of impacts due to past disposal practices and the understanding that gas plant wastes contain a wide range of chemical constituents that have persisted in the environment.

This paper discusses the history of the town gas plant industry, the various processes utilized and the resultant by-products and wastes. Potential problem areas relating to these sites as well as potential approaches to site characterization are addressed. Included are recommendations for the phasing of site investigations and the use of relatively inexpensive and rapid field screening techniques to identify contamination.

INTRODUCTION

Town gas plants, utilized throughout the United States in the late 1800s and early 1900s to manufacture gas for illumination, cooking and heating purposes, are of growing concern to the utility industry and regulatory communities. These plants (well over 1,000 across the country), as well as gas storage holders, gas cleanup areas and waste and by-product disposal areas, are undergoing scrutiny because of the array of wastes that were generated and/or disposed of at many of these sites. The wastes commonly found at these sites can contain heavy metals, cyanides, phenolics, polynuclear aromatics and volatile compounds. Some of these chemical constituents can be characterized as mobile, while others are persistent in the environment.

This paper discusses the history of town gas plants, the potential problems posed by town gas plant sites and site characterization procedures to evaluate these sites. Cost-saving field screening techniques developed to identify volatiles and polynuclear aromatic compounds will be discussed.

This paper also will discuss a ranking system that has been implemented successfully to prioritize site characterization at multiple sites. This system will interest utilities confronted with multiple site evaluations. In some cases, this ranking system has been used as a basis for selecting the no action alternative.

HISTORY OF TOWN GAS PLANTS

Town gas plants had their roots in the 1700s with the discovery that coal carbonization was a major means of producing coal gas, coal tar, light oils, coke and ammonia liquor. These by-products were utilized as source materials for the production of various materials used in diverse industries. Manufactured gas was initially a major source of fuel for illumination in many cities in England, Germany and the United States. The uses of manufactured gas expanded to include those which utilize natural gas today.

In addition to manufactured gas, the use of coal tars and light oils grew to major importance in the chemical manufacturing industry. The tars and oils were used as base materials for the formulation of a variety of products, including paints and coatings, road tars, roofing and water-proofing materials, pipeline enamels, fiber conduit and fiber pipe saturants, carbon electrode binders, foundry compounds, industrial fuels and wood preserving oils and chemicals. The refined chemicals from coal tar and light oil were the starting materials for synthetic organic chemicals of the day, including dyestuffs, drugs, disinfectants, insecticides, antiseptics, flavoring components, vitamins, food preservatives, perfumes, photographic materials in both the domestic (coke only) and industrial sectors.

The manufactured gas industry in the United States became prominent during the two world wars. Peak production of coal tar products in the U.S. occurred in the years prior to World War II. This era was a period of marked changes in coal tar product patterns. Petroleum asphalts became favored over road tars produced from coal and demand decreased dramatically. Creosote production fell mainly because of the reduced demand for creosoted crossties by American railroad lines. Light-oil recovery decreased due to foreign imports and the growing use of petroleum-derived products. Finally, as natural gas became available by pipeline in the northeast, it was no longer economically feasible to maintain aging facilities which produced manufactured gas for domestic use.

MANUFACTURED GAS PROCESSES

The manufactured gas processes changed significantly over the years that the industry operated. However, the basic process consisted of the following three general operations:

- Distillation—heating coal, coke or oil to drive off or crack organic carbon-based materials (in the presence of steam, in some cases)
- Condensation—cooling the manufactured gas to remove the condensible fraction (tars)
- *Purification*—washing and/or making contact with iron oxidesoaked chips and other materials to remove toxic materials from the gas

In addition to these three processes, enrichment processes were utilized in some cases. For example, carburetion was one of the earliest enrichment processes in which a petroleum distillate was mixed with the hot gases and cracked in a brick chamber. Later enrichment processes utilized catalysts to modify the chemical makeup of the gas constituents.

Manufactured gas was generated from many different processes; however, there are five basic types into which all of these processes generally fell: blue gas, carbureted water gas, coke oven gas, catalytically cracked gas and oil gas.

Blue gas (or water gas) was a mixture of carbon monoxide and hydrogen with a heating value of approximately 300 Btu/ft³. The blue gas was produced by passing steam over coal or incandescent coke with a resultant endothermic reaction. A cyclic process of air blasts was used to control the temperature and thereby minimize the production of excess nitrogen and carbon monoxide. Figure 1 is a flow diagram of a typical blue gas producer.

Carbureted water gas was basically an enriched blue gas. Hot blue gas was enriched in a carburetor with a petroleum distillate (e.g., Bunker C) and then passed through a superheater (e.g., a preheated brick chamber) to crack the distillate. Figure 2 is a flow diagram of a typical water gas producer. The process was cyclical to control excessive nitrogen and carbon dioxide contamination of the gas and reduce the overheating of the carburetor and superheater.

Coke oven gas was a mixture of hydrogen, methane, carbon monoxide and illuminants (e.g., ethylene) with a heating value of approximately 500 Btu/ft³. The gas was produced in steel coke ovens and normally was cleaned at the steel manufacturing plant to remove tars, ammonia, light oils, naphthalene and some sulfuric compounds which were sold as separate by-products. Figure 3 is a flow diagram of a typical coke oven gas process.

Catalytically cracked gas was a mixture of carbon monoxide and hydrogen with a heating value of approximately 300-400 Btu/ft³. This process was similar to carbureted water gas in that a low Btu was enriched by cracking a petroleum distillate over a nickel oxide catalyst with regulated amounts of steam.

BLUE GAS PRODUCER GAS PROCESS FLOW



Figure 1

CARBURETED WATER GAS PRODUCER GAS PROCESS FLOW



Figure 2

Oil gas was basically a cracked petroleum distillate (i.e., ranging from kerosene to Bunker C fuel oil). The oil gas was rich in methane, ethane, hydrogen and light hydrocarbons with a heating value of approximately 1,000 Btu/ft³. The thermal cracking of the

COKE OVEN GAS PROCESS FLOW



rigule 5

petroleum distillate was achieved by spraying it onto hot brickwork (e.g., a superheater similar to that utilized in the production of carbureted water gas) or a bed of hot catalyst.

BY-PRODUCT/WASTE GENERATION

By-products and wastes generated by the processes of coal/coke gasification, gas cooling and gas cleaning are linked below:

Process	By-products	Wastes
Coal/Coke Gasification	Gas	Ash, slag and clinkers
Gas Cooling	Tar	Wastewater and sludges
Gas Cleaning	Clean Gas	Spent iron oxide
	Ammonium Sulfate	

Gas cooling resulted in the condensation of organic material that was removed as tar. Gas cleaning was performed to remove ammonia and toxic compounds. Ammonia scrubbing occurred primarily at coke oven gas facilities. Other facilities which produced carbureted water gas and catalytically cracked gas did not typically include ammonia scrubbing. The removal of ammonia occurred by simply passing the gas stream through a sulfuric acid solution with the resultant formation of ammonium sulfate that was normally sold for the production of fertilizer.

Subsequent to tar removal, toxic compounds (i.e., hydrogen sulfide and cyanide) were removed. The most common process for the removal of these compounds utilized fixed bed purifier boxes. The purifier boxes contained wooden chips that were treated with iron oxide which was used as a scavenger for hydrogen sulfide in the gases. The iron oxide was regenerated by cycling the purifier boxes (i.e., blowing air through the beds, thereby releasing sulfur dioxide into the atmosphere). Over time, the iron oxide/wood chip beds lost their usefulness because of the formation of extremely stable ferric/ferrous cyanide complexes on the wood chips.

ENVIRONMENTAL CONCERNS

In the evaluation of manufactured gas plant sites, the areas of potential concern result primarily from the following past practices:

- Spills and leaks of products/by-products during normal operation and closure of facilities
- Products/by-products that may not have been utilized or were left in place during closure (e.g., left in process pipes and tanks)
- Wastes that were deposited on-site or off-site
- · Wastewaters that were discharged on-site and off-site

The specific environmental concerns relative to these operations and/or practices include:

- Leaching of metals from ash, slag and clinkers land-filled on-site
- Contamination of soils, groundwater, or surface water by spent iron oxide which contains high concentrations of sulfur and significant concentrations of various cyanides. Table 1 summarizes compounds that may be identified in spent oxide waste
- Contamination of soils, groundwater or surface water by tars and light oils. These wastes typically are a complex mixture of polynuclear aromatic (PNA) compounds and phenols as shown in Table 2. Environmental concerns stem from the fact that some of these compounds are known or suspected carcinogens

Table 1Typical Analysis of Spent Oxide2

Compound	Concentration (%)
Free sulfur	44.70
Moisture	18.88
Ferric monohydrate	5.26
Ferrous monohydrate	6.25
Basic ferric sulfate	1.25
Ferric ammonium ferrocyanide	3.80
Ferrocoferric ammonium ferrocyanide	2.50
Ferric pyridic ferrocyanide	1 20
Organic matter peat fiber	4.68
Tar	1.21
Silica	1.05
Naphthalene	0.72
Pyridine sulfate	0.77
Ammonium sulfate	2.06
Calcium sulfate	0.12
Ferrous sulfate	0.02
Ammonium thiocyanate	1 30
Sulfur otherwise combined	1 33
Organic matter soluble in alkalies	1.55
(humus)	1 54
Combined water and loss (by difference)	2 36
combined water and loss (by unreferice)	2.30
	100.0

 Table 2

 Characteristic Compounds Found In Manufactured Gas Plant Tars¹

Benzene Toluene Xylenes Phenol Cresols Xylenols Pyridine Naphthalene Methylnaphthalenes Dimethylnaphthalenes Acenaphthene Carbazole Fluoranthene Anthracene Phenanthrene Fluoranthene Pyrene Chrysene Benz(a)anthracene Benzo(k)fluoranthene Benzo(a)pyrene Perylene Benzo(g,h,i)perylene Benzo(b)chrysene Dibenz(a,h)anthracene The major steps in conducting site investigations and remedial studies at town gas plants are as follows:

- Site Identification/Preliminary Assessment
- Site Ranking
- Phased Site Investigations
- Identification of Problem (Risk Assessment)
- Evaluation and Selection of Remedial Measures

The balance of this paper overviews each of the first three steps of the preceding paragraphs.

Site Identification/Preliminary Assessment

Identification by a utility of town gas plant sites for which it is responsible can be prompted by:

- Complaints of visible contamination either at the site or as a result of a discharge to surface water
- Interaction with other utilities due to current and/or prior ownership of a town gas plant site
- Follow-up Superfund 103CC filings on these sites
- Regulatory inquiries
- Internal concerns relative to the potential existence of these sites

Once identified, a preliminary assessment of the site to gather site-related information is advisable. This assessment should identify the potential for on-site by-product deposits, site features that would indicate potential exposure pathways and available information on site stratigraphy, geohydrology and community attitudes that would be used to design the site investigation program.

Examples of potential sources of information that can be used for the preliminary assessment are identified in Table 3. The overall objective of Site Identification/Preliminary Assessment is to develop a data base from which sites can be evaluated as to the need for future action. In such cases where a utility may have responsibilities at multiple sites, site ranking typically is utilized to prioritize the subsequent evaluations. Our firm has found cases where no further investigation was deemed necessary based upon preliminary assessments.

Table 3 Potential Sources of Information For The Preliminary Assessment

Source	Information/Remarks		
Interviews with Former Employees	 Plant practices and operation Waste disposal areas Plant closure 		
Water Resource Department (or equivalent)	 Location of wells (domestic and industrial) in site vicinity Well boring logs (site stratigraphy) Water quality 		
Utility Records	 Past plant practices and operations Aerial photographs Title searches Former plant layouts 		
State/Local Agencies	 Regulatory requirements Study objectives Results from prior studies 		
US FEMA	• Location in 100-year flood plain		
US Soil Conservation Service	 Classification of soils in site vicinity 		
USGS	Location of wellsTopographical maps		
Site Visit	 Evaluate site conditions Evidence of contamination Impediments to site investigations Adjacent land use 		

Reference: ERT/Koppers,(2)

Site Ranking

For utilities faced with multiple site evaluations, site prioritization may be appropriate and desirable to allocate resources in a costeffective manner. Advantages include:

- Dedication of utility resources to those sites that are considered the most important and require additional site investigations
- A sound basis for developing site investigation schedules for multiple sites
- Prioritization of sites in response to regulatory agency inquiries

WESTON uses a modification of the Edison Electric Institute Ranking System in its approach to ranking town gas plants². The system results in a relative ranking of site importance based on the following factors:

- Site Characteristics
 - Size
 - Location
 - Current Use
 - Planned Use
- Waste Characteristics
 - Operating Period
 - Visible Surface Waste Deposits
 - Odor Problems
 - Water Problems
- Resource Characteristics
 - Surface Water Proximity
 - Surface Water Use
 - Groundwater Proximity
 - Groundwater Use
- Process Type

For each subcategory under Site, Waste and Resource Characteristics, and for the category of Process Type, a site is ranked on a scale of 1 to 5. A score of 1 indicates little importance, while a score of 5 indicates high importance. The site score is the sum of the individual scores and the site with the highest score is ranked the most important (i.e., recommended for additional site investigations).

Phased Site Investigations

Site investigations are conducted to achieve the following objectives:

- Confirm the presence of plant by-products and wastes at a site due to former town gas plant operations as well as determine the lateral and vertical extent of the source material
- Determine the direction, rate and concentrations of constituentsof-concern moving off-site
- Gather adequate site information to assess potential site problems and, if necessary, develop and select remedial measures
- Determine if any immediate remedial measures should be implemented to mitigate environmental concerns

A phased approach is strongly recommended to cost-effectively achieve the above-listed objectives. In addition, phasing allows utilization of information from a previous phase to guide subsequent phases of potential activity.

An example of a phased field investigation program for a gas

plant site is summarized below:

Phased Field Investigation Program

Phase 1—Shallow soil and sediment samples are collected onsite for full priority pollutant analysis. Based on the results, "indicator" parameters are selected for analysis in subsequent phases. The results of the shallow soil sampling will indicate if the site poses any immediate threats and whether site access should be restricted. During sample collection, volatile aromatic and PNA field screening techniques are applied. Correlations can be identified between field and laboratory results and used in subsequent investigation phases.

Phase 2—Test pits are subsequently excavated to locate the source material on-site. Additional soil samples are collected and analyzed for the "indicator" parameters. During backfilling, piezometers are placed down to the groundwater table in selected test pits. These piezometers are surveyed and used to measure groundwater levels to determine groundwater direction.

Phase 3—Upgradient, downgradient and on-site wells are installed based on the groundwater flow direction identified. After well development, groundwater samples are collected for chemical analysis. Permeability testing is performed to derive soil permeability data and calculate groundwater flowrates.

Field screening methods are expedient, effective and inexpensive ways to locate the lateral and vertical extent of contamination. Even during intense soil sampling efforts at a site, field screening can be used to increase knowledge of the site. Relevant to town gas plant sites, our firm has developed and had the U.S. EPA validated field screening methods for the determination of total polynuclear aromatics (PNAs) and volatile aromatics in both soils and water.

The PNA screening method, which is being implemented at two Superfund sites, consists of rapid extraction and analysis using UV flourescence spectrophotometry. The volatile aromatic screening technique entails collection of a headspace sample from a field sample in a closed container. The gaseous sample then is injected into a portable gas chromatograph (Photovac model 10A10).

CONCLUSIONS

Gas plant wastes contain a wide range of chemical constituents that have persisted in the environment. The approach to site characterization should consist of site identification/preliminary assessment, site ranking and phased site investigations. Site ranking can be used to prioritize multiple sites for further investigations. In some cases, this ranking system has been used as a basis for selecting the No Action alternative.

The phasing of site investigations results in cost savings through the use of field screening techniques, "indicator" parameters for analysis and the collection of on-site data prior to investigating off-site locations. Finally, WESTON has developed field screening techniques for volatile aromatics and PNAs, two classes of compounds typically found in town gas plant wastes. Advantages in using these methods include reductions in laboratory costs, quicker turnaround times and greater knowledge of site contamination.

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Dioxin Contamination at Historical Phenoxy Herbicide Mixing and Loading Locations

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ABSTRACT

A field study was performed to determine if 2,3,7,8-TCDD persists in a former phenoxy herbicide use area. A search of historical records determined the exact kinds and amounts of herbicides used. The study focused on helicopter landing spots (helispots) where the herbicides were mixed and loaded prior to application. Product spillage and rinsate disposal from spray operations likely would have occurred at these locations.

Soil samples were collected at five helispots. Surface drainage pathways from the helispots were sampled to assess migration via particulate transport. Sediment samples were obtained from nearby streams. Wildlife from the area were collected to measure dioxin levels in animal tissue. Background, duplicate and blank samples were included with the soil samples for quality assurance purposes. Duplicate samples of animal tissue were included when sufficient tissue volume existed.

High resolution GC/MS analyses of the soil samples detected dioxin at three helispots and in some soil samples at short distances from the mix and load areas. Dioxin was not detected in the sediment and wildlife samples.

INTRODUCTION

The U.S. EPA initiated the National Dioxin Study to determine the extent of dioxin contamination in the United States. The U.S. EPA focused on 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) because it is considered the most toxic of the 75 chlorinated isomers of dioxin. Exceptionally low doses of 2,3,7,8-TCDD elicit both acute and chronic toxicity in animals. 2,3,7,8-TCDD is the most potent animal carcinogen evaluated by the U.S. EPA and is a potential human carcinogen.¹

2,3,7,8-TCDD is formed as an inadvertent contaminant in the manufacture of trichlorophenol. Subsequent derivatives of trichlorophenol include the herbicides 2,4,5-T and Silvex which were used primarily to control weeds on rice, rangeland, forests and rights-of-way. All uses of 2,4,5-T and Silvex now are banned in the United States.

The National Dioxin Study investigated locations where trichlorophenol and its derivatives were manufactured, formulated and used. The U.S. EPA identified 20 trichlorophenol production facilities with 79 associated waste disposal sites and 637 potential formulation locations where the herbicides were blended and packaged for distribution. The U.S. EPA selected a number of herbicide use areas for sampling. This paper discusses residual levels of 2,3,7,8-TCDD at one such herbicide use area in a national forest.

BACKGROUND

From 1965 to 1969, the phenoxy herbicides 2,4-D, 2,4,5-T

and silvex were aerially applied in the Globe Ranger District of the Tonto National Forest near Globe, Arizona. This herbicide use project was designed to improve rangeland and to increase water runoff, resulting in increased water yields for downstream users.

Complaints regarding spray drift, deformed animals and human illness were received immediately after the 1969 spray treatment. The U.S. Forest Service convened two task forces and an interdepartmental panel of experts to assess the health and environmental consequences of the herbicide project. Silvex was detected in some environmental samples collected. 2,3,7,8-TCDD was detected at 0.5 ppm in one sample of unused herbicide. However, laboratory methods had not yet been developed to analyze environmental samples for 2,3,7,8-TCDD in the low ppb or ppt ranges.²

Several lawsuits were filed after the 1969 spray season.³ The lawsuits gained national attention and became known as the Globe Spray cases. Due to the litigation, the U.S. Forest Service maintained the records relating to all 4 years of herbicide use in the Globe Ranger District.



Figure 1 Location of Herbicide Use Area

SITE SELECTION

The study area was selected because accurate records existed from the 1965-1969 spray season. In addition, the herbicides were used prior to 1970 when levels of 2,3,7,8-TCDD in 2,4,5-T and Silvex were limited by the Federal government.⁴ A review of Federal and state regulatory agency files did not indicate any subsequent herbicide applications. Fig. 1 shows the location of the herbicide use area selected for study.

PREPARATION OF A SAMPLE PLAN

The study was designed to determine if 2,3,7,8-TCDD could be detected 15 years after herbicide usage. Historical records were reviewed and a sample plan was prepared that detailed the original herbicides used and the soil, sediment, wildlife and field quality assurance samples necessary to meet the study objective. A thorough discussion of the elements of a sample plan is presented elsewhere in these proceedings.³

Field sampling techniques were incorporated into the sample plan by reference to guidance prepared specifically for the National Dioxin Study.⁴ Laboratory analyses and quality assurance were also specified.⁴

Herbicide Use

A review of U.S. Forest Service files determined the exact kinds, amounts and locations of the herbicides used. Table 1 contains a summary of this information.

Soil Samples at Helispot Locations

Sample points were focused on areas most likely to be contaminated. These areas were the helicopter landing spots (helispots) where the herbicides were mixed and loaded prior to application. Product spillage and disposal of rinsate from spray operations likely would have occurred at these locations.

U.S. Forest Service files were reviewed for narrative accounts and maps dating from the herbicide use project. While the maps indicated a number of helispot locations, there was uncertainty whether specific helispots had been used for herbicide mixing and loading or for routine fire suppression purposes.

Knowledge of herbicide operations clarified the distinction between fire suppression and herbicide mixing and loading helispots. A fire suppression helispot is a flat, prominent location where a helicopter could land to deploy or retrieve firefighters. A helispot used for herbicide operations would have two levels: an upper level for helicopter landing, and a lower level where the 55-gal drums of herbicide and mixing equipment would be located.

Interviews with the original spray crew indicated that three helispots had been used for the entire herbicide use project. Historical aerial photographs were examined for ground scars which confirmed that heavy equipment had prepared the three helispots coinciding with the herbicide use period.

Sediment Samples

2,3,7,8-TCDD adheres to soil and is transported along surface drainage patterns. Creeks and stock tanks downgradient from the herbicide use area were identified for sediment sample collection. Topographic maps were examined and field observations were made for sediment deposition areas. Kellner Creek, loehouse Creek, Pinal Creek and Blue Tank receive drainage from the herbicide use areas and were selected for sediment sample collection.

Dates of Application	Chemical Name	Manufacturer	USDA Reg.(a) Number	Application Rate(b) (lbs per acre)	Total Acres Treated	Total(b) Application	
August 23,24, 25, 1965	2,4-D, isooctyl ester	Monsanto	524-115	1 16) 496	3300 lbs	
	2,4,5-T, isooctyl ester	Thompson- Hayward	148-431	1 1b_	1,490	3300 103	
May 7,8, 1966	2,4-D, isooctyl ester	Monsanto	524-115	1 1b ⁻ 2 1bs 1 1b ₋	1,060	1980 lbs	
	2,4,5-T, isooctyl ester	Thompson- Hayward	148-431				
May 31, June 1,2,3, 1968	Silvex, propylene glycol butyl ether ester	Dow	464-162	2 1bs	1,800	3520 1bs	
June 8,9,10, 11, 1969	Silvex, propylene glycol butyl ether ester	Dow	464-162	2 lbs	1,900	3740 lbs	
	2,4-D, isooctyl ester	Monsanto	524-115	1 16	Estimate of 24 gallons solution remaining in project spray tanks from previous project.		
	2,4,5-T, isooctyl ester	Th ompson- Hayward	148-431	1 1b_			
	2,4,5-T, butyl ester	Hercules	891-46	30 gallons of un 2 lbs material leftove 1966 demonstrati material applied 2 lbs of operations.		ons of undiluted l leftover from	
	2,4,5-T, 2-ethylhexyl este	r Hercules	891-45			plied at start	

Table 1 Summary of Herbicides Used

notes: (a) USDA Pesticide Registration Numbers were converted to EPA Pesticide Registration Numbers in 1971. (b) All pounds indicated are pounds acid equivalent for the herbicides used.

HERBICIDE USE AREA 1965-1969



Figure 2 Location of Helispots Within the Study Area

Wildlife Samples

State biologists indicated that many wildlife species were available for sampling including deer, javelina and coyote. Fish from stock tanks also could be collected. Arrangements were made with the Arizona Department of Game and Fish for a scientific collector's permit and assistance in sample collection. Arrangements also were made with a local veterinarian for removal of target tissues (kidney, liver and fat) from large game animals such as deer and javelina. Small animals were to be submitted whole for analysis.

Quality Assurance

Soil and sediment samples were planned to include at least 10% duplicate samples, laboratory-certified organic-free blank samples and performance evaluation samples. Background samples were proposed from the top of Pinal Mountain, upgradient from the former herbicide use area. The U.S. Forest Service verified that herbicides had never been applied in the background sample collection area.

For quality assurance in the wildlife samples, subsamples of the large game tissues were to be obtained by the project veterinarian when sufficient volume existed.

SAMPLE COLLECTION

Soil and Sediment Samples

Each helispot was divided into equal-area grid cells, and a soil sample was obtained from the center of each cell.

The soil sampling device described in the sample plan was a 4-in. deep tulip bulb planter so that equivalent samples could be collected throughout the study. However, this sampling device proved difficult to use in the field, as it could not penetrate the hard and rocky ground. Garden trowels were substituted for the tulip bulk planters, and the sampling personnel were instructed to obtain 4-in. deep samples. Soil samples also were collected at the bottom of small gullies leading from the helispots where fine particulate settled.

Sediment samples were collected at each of the locations as described in the sample plan. All soil and sediment samples were put in precleaned and prenumbered quart jars, taped shut and placed on ice for preservation.

Wildlife Samples

Animals were collected in and near the former herbicide use area. The large game were shot and the freshly killed animals taken to the local veterinary clinic. The veterinarians completed necropsy reports and removed kidney, liver and fat tissues. Other animal tissues were preserved in formalin, to allow for future histological examination if the analytical results from target tissue indicated the presence of 2,3,7,8-TCDD.

A variety of methods were used to collect the smaller animals. Table 2 details the wildlife collected. All whole animal and animal tissue samples were wrapped in aluminum foil and frozen as soon as possible after collection or preparation. Three animal tissue subsamples (deer fat, javelina liver and javelina fat) were



Sample Points at Helispot #1

submitted in duplicate. Several of the stock tanks had dried up since the prior reconnaissance trip and no fish were available for collection.

LABORATORY ANALYSES

All soil, sediment and wildlife tissue samples were shipped to U.S. EPA laboratories for high resolution GC/MS analyses. To achieve Quality Assurance and Quality Control objectives, general requirements for data comparability, data representativeness and data completeness were established under the National Dioxin Study. Specific data quality objectives for analyses also were defined (e.g., precision, bias, minimum levels of detection and isomer specificity). All data were reviewed and validated.

RESULTS

Soll Samples

2,3,7,8-TCDD was detected at both Helispots #1 and #2 (see Fig. 4 and 5, respectively). Two analytical. values are reported at duplicate sample locations. 2,3,7,8-TCDD was detected in every soil sample collected from the uppermost levels at Helispots #1 and #2. 2,3,7,8-TCDD also was detected in some soil sampl.es taken in the small gullies leading away from Helispots #1 and #2.

At Helispot #3 (Fig. 6), 2,3,7,8-TCDD was not detected in any of the soil samples.

Detection limits for the soil samples were examined. Detection limits at Helispot #3 ranged from 1.0 to 3.0 ppt. Detection limits at Helispots #1 and #2 ranged from 1.0 to 9.0 ppt. Since detection limits were generally lower at Helispot #3, detection limits could not account for non-detectable levels at this location. All values reported for duplicate samples were within acceptable ranges for the study. One explanation for non-detectable levels of 2,3,7,8-TCDD at Helispot #3 was that it had not been used for herbicide mixing and loading.

Sediment Samples

2,3,7,8-TCDD was not detected in the sediment samples from Kellner Creek, Icehouse Creek, Pinal Creek and Blue Tank. Detection limits ranged from 1.0 to 3.0 ppt for these samples.

Wildlife Samples

2,3,7,8-TCDD was not detected in any of the animal tissue analyzed. Detection limits ranged from 0.2 to 9.7 ppt. With the exception of the fat samples from the deer, javelina and coyote, the detection limits for the other wildlife samples ranged from 0.2 to 1.7 ppt. The fat samples apparently contained other chlorinated compounds which interfered with 2,3,7,8-TCDD analysis and resulted in higher detection limits. One sample of deer kidney could not be analyzed due to insufficient volume.

Preliminary Conclusions

The soil sample analyses indicated that 2,3,7,8-TCDD did persist at the herbicide mixing and loading locations. Two of the three helispot samples were contaminated in the ppt range. A followup study was proposed to determine if contamination had been adequately characterized within the study location.

FOLLOWUP INVESTIGATION

Subsequent investigation provided more information on the original herbicide use project. Helispot #1 was the only location used for all four spray years. Kellner Creek was downhill from this helispot and provided water for herbicide dilution and rinsing of spray tanks and equipment. The rinsate reportedly was disposed on the lower level of Helispot #1. The initial sampling may not have fully characterized this helispot, because the lower level had not been sampled.

Further investigation was performed to account for the nondetectable levels at Helispot #3. Records and interviews established that Helispot #3 had been used for at least 3 of the 4 years of the herbicide use project. A return visit to Helispot #3 revealed a nearby location with herbicide use artifacts including 55-gal drum bung hole covers, a funnel and pieces of hose. These artifacts pinpointed the actual mixing location for Helispot #3.

The investigation also identified two other helispots which may have been used. One location, identified as Helispot #4, was used in 1969 for an emergency landing on a concrete pad after a spray hose broke as the helicopter passed between Kellner and Icehouse Canyons.

The other location, identified as Helispot #5, was on a hilltop adjacent to a residence. While there was no evidence the helispot had been used for herbicide mixing, the residence was near the 1965-1969 herbicide use area and the study had alarmed the current residents.

FOLLOWUP SAMPLE PLAN

Soil Sampling

A sample plan for followup study was prepared. The areas slated for sample collection were: Helispot #1 (lower level), Helispot #3 (mixing location), Helispot #4 (1969 emergency landing
Table 2Summary of Wildlife Collected

Common Name Scientific Name	Sex	Age	Weight	General Location	Collection Method	Tissue Sampled
Coyote <u>Canis latrans</u>	Female	8 months	Ünknown	W of Russell Gulch N of Spray Area	Shot	Liver, Kidney, Fa
Black Rattlesnake <u>Crotalus</u> <u>spp.</u>	Unknown	Unknown	Unknown	Icehouse Canyon Near Helispot #3	Shot	Whole
Deer <u>Odocoileus</u> virginianus	Male	l year	57 lbs	W of Road 651 Near Helispot #2	Shot	Liver, Kidney, Fa
	Female	Fawn	23 lbs	W of Road 651 Near Helispot #2	Shot	Liver, Kidney, Fa
Javelina Dicotyles <u>tajacu</u>	Male	Unknown	50 lbs	W of Russel Gulch S of Rock Tanks	Shot	Liver, Kidney, Fa
	Male	Unknown	56 lbs	W of Russel Gulch S of Rock Tanks	Shot	Liver, Kidney, Fa
Glossy Snake <u>Arizona elegans</u>	Unknown	Unknown	Unknown	Kellner Creek at Kellner Campground	Captured by Hand	Whole
Gambel's Quail Lophortyx gambelli	Female	Unknown	Unknown	Kellner Canyon near Road 112C	Shot	Whole
Garter Snake Thamnophis radix	Unknown	Unknown	Unknown	Blue Tank	Captured by Hand	Whole
Toad Bufo cognatus	Unknown	Unknown	Unknown	Blue Tank	Netted	Whole
Leopard Frogs Rana pipiens	Unknown	Unknown	Unknown	Blue Tank	Netted	Whole Composite



Figure 4 Analytical Results at Helispot #1



VALUES REPORTED = pg/g = Parts Per Trillion Figure 5 Analytical Results at Helispot #2





spot) and Helispot #5 (adjacent to residence). Fig. 7 shows the locations of these helispots for followup study.

Figure 7

Fish Sampling

ONE MILE

Stock tanks located near Helispot #5 may have been in the helicopter's path when the spray hose broke in 1969 and may have received spray material. Fish collection was proposed.

SAMPLE COLLECTION

Soil samples were collected in similar fashion to the initial study. The lower level at Helispot #1 was divided into equal-area grid cells and a soil sample obtained from the center of each cell. Samples were collected adjacent to the herbicide use artifacts at Helispot #3 and randomly across this open location. Samples were collected immediately downgradient of the only two concrete pads at Helispot #4 and from the small gullies nearby. This area currently is used as a public picnic area.

Rather than sample Helispot #5 itself, soil samples were collected in small eroded gullies leading from the helispot through the residential property. These samples would determine actual levels on the residential property, and any detectable values could be used for risk assessment purposes.

Background and duplicate samples were included with each soil sample set. One composite sample of whole sunfish was collected from a stock tank. Sufficient sample volume did not exist for a duplicate fish sample.

RESULTS

Soil Samples

All samples collected from the mixing area at Helispot #1 contained 2,3,7,8-TCDD, with levels ranging from 43 to 6623 ppt. The upper value is the highest level of 2,3,7,8-TCDD reported at any herbicide use area sampled under the National Dioxin Study. A soil sample collected 25 ft downgradient from the mixing area contained 2,3,7,8-TCDD at 195 ppt.



2,3,7,8-TCDD was also detected in all samples collected at the mixing location for Helispot #3. The highest values at this location were the duplicate samples collected adjacent to where a funnel and pieces of hose were found. These duplicate soil samples indicates 2,3,7,8-TCDD and 2317 ppt.



VALUES REPORTED = pg/g = Parts Per Trillion. Δ Location of Herbicide Use Artifacts

Figure 9 Analytical Results at Helispot #3 (Mixing Location)



VALUES REPORTED = pg/g = Parts Per Trillion

Figure 10 Analytical Results at Helispot #4



VALUES REPORTED = pg/g = Parts Per Trillion

Figure 11 Analytical Results at Helispot #5

All soil samples collected at Helispot #4 were non-detectable with detection limits which ranged from 0.08 to 0.33 ppt. All soil samples collected at Helispot #5 were non-detectable with detection limits which ranged from 0.08 to 0.26 ppt.

Fish Sample

2,3,7,8-TCDD was not detected in the composite sample of whole sunfish collected at the stock tank near Helispot #5, at a detection limit of 0.44 ppt.

CONCLUSIONS

Detectable levels of 2,3,7,8-TCDD may persist at historical phenoxy herbicide mixing and loading locations where product spillage and rinsate disposal have occurred. 2,3,7,8-TCDD also was found at short distances from the mixing and loading areas. Dioxin was not detected in stream sediment or wildlife samples collected. Other herbicide mixing and loading locations, such as those found in agricultural areas and used over longer periods of time, may contain levels of 2,3,7,8-TCDD in excess of values reported in this study.

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Field Screening Techniques Developed Under the Superfund Program

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ABSTRACT

Field screening techniques were developed by WESTON for the Superfund Program to accommodate the increasing data requirements associated with Remedial Investigations/Feasibility Studies. Techniques have been developed for application at National Priority List (NPL) sites for field analysis of two classes of contaminants: (1) polynuclear aromatic hydrocarbons (PNAs) and (2) volatile organics.

The methods for screening PNAs and volatile organics were developed in the laboratory and validated by comparison with standard laboratory analysis. The method for screening PNAs, consisting of a one-step field extraction followed by a UV fluorescence spectropthotometric analysis, was developed for determination of total PNAs in soil and water samples.

The volatile organic screening method was developed for detection of 1,1-dichloroethylene, 1,1,2-trichloroethylene and 1,1,2,2-tetrachloroethylene in a water matrix. This method utilizes a head space analysis with a Photovac portable gas chromatograph at ambient conditions.

Each of the three screening techniques is a reliable method of analysis of its respective contaminants and was successfully implemented in the field at different NPL sites. In addition, the field application of these techniques demonstrated rapid turnaround times for sample analysis and the cost-effectiveness of field screening.

INTRODUCTION

The Remedial Investigations/Feasibility studies (RI/FS) process for NPL sites under the Superfund Program often have been prolonged because of data requirements. Many factors, including issues relating to liability, quality assurance, enforcement and cost recovery have contributed to significant increases in the amount of data necessary for completion of a RI/FS. As a result, the associated schedules and costs to conduct the studies have increased accordingly.

In an effort to expedite the RI/FS process, the U.S. EPA has encouraged the development of field screening techniques. These techniques allow a more focused, more complete, expedient and cost-effective field effort during the RI. The major advantages of the field screening techniques include:

- Rapid turnaround times enabling cost-saving field decisions
- Analysis of a larger number of samples in the field
- Ability to redirect and focus sampling efforts thereby increas-

ing the accuracy of estimates of zones of contamination and shortening field schedules

• Optimum selection of samples for off-site laboratory analysis by standard methods

Fig. 1 demonstrates how screening techniques can be incorporated into an RI/FS.

This paper summarizes two field screening techniques that were developed for and implemented at NPL sites during fiscal years 1985 and 1986. These include screening techniques for field analysis of the following classes of contaminants:

- PNAs soil, water and sediment
- Volatile organics in water

This paper presents an overview of the method development procedures for the field screening techniques. The analytical methods, equipment requirements, typical costs for implementation, anticipated sample throughput, examples of typical site applications and technique limitations are discussed in this paper.

DESCRIPTION OF FIELD SCREENING TECHNIQUES

PNA Screening Technique

This field technique is a rapid semi-quantitative analytical method for determining total PNAs in soil, sediment and water samples (i.e., for contamination assessment at wood treating sites). The method yields a total concentration of PNAs which is comparable to the sum of individual PNA compound concentrations obtained from conventional analytical methods (e.g., U.S. EPA-CLP Protocol).

This screening technique utilizes a UV fluorescence spectrophotometer as the detection instrument. The fluorescence spectrophotometer uses ultraviolet light to excite electrons which will emit light at certain wavelengths when returning to their initial state. Different chemical compounds and concentrations of these compounds in a mixture are determined by the varying degrees that they absorb a particular wavelength of light (i.e., different instrument response values). The instrument response is displayed digitally and on a chart recorder.

The UV spectrophotometer is calibrated using standard solutions with known concentrations of PNAs in acetonitrile or hexane. Measured quantities of each field sample are extracted with acetonitrile (from soil or sediment) or hexane (from water) solvents in an on-site laboratory. A sample of the extract is then



Figure 1 Use of Field Screening Techniques in Remedial Investigations/Feasibility Studies

analyzed using the UV instrument and the PNA concentration is readily calculated using the measured instrument response and the calibration curve. The instrument operating conditions are shown in Table 1.

Volatile Organic Screening Technique

This technique is a quantitative analytical method for determination of 1,1,2,2-tetrachloroethylene, 1,1,2-trichloroethylene and 1,1-dichloroethylene in water using a portable GC. The results of the field screening technique correlate well with analytical data obtained by conventional laboratory analysis.

This screening technique utilizes a portable GC—the Photovac Model 10A10. The Photovac Model 10A10 uses gas chromatography to separate the components in the gaseous mixture, followed by detection using UV light. Molecules having ionization potentials greater than that of the ultraviolet light source (11 electron volts) are less likely to be ionized. Once the molecule is ionized by the UV Energy, the resulting charged particles are captured in an electric field and detected with a sensitive electrometer which amplifies the current for display on a recorder.

Table 1 Method Detection Limits and Operating Conditions					
Screening Technique	Parameter	Retention Time (min)	Method Detection Limit (ug/1)		
Volatile Organica ¹	1,1-Dichlorosthylene	0.62	1.0		
	1,1,7-Trichloroethylene	3.32	1.0		
	1,1,2,2-Tetrachloroethylene	9.68	2.0		
PHA ²	Total PRAS-Soil/solvent		1-10 ppm (ug/g)		
	Total PNAS- Water	-	10.0		

1. Gas Chromatograph Column Conditions:

Chromatograph column conditions: 1.5' SE-30 support and 4 coating unknown. Helium carrier gas at 20 ml/min to establish method detection limits. High grade air at 20 ml/min in actual field use. Ambient temperature.

1. UV Fluorescence Spectrophotometer Conditions: Response = 0 Fixed Scale = 0.1 Recorder Scale = 1000 mV Slit width: excitation 10 mm, emission 10 mm <u>Wavelength pairs</u> Excitation Emission Pair 1 280 340 Pair 2 250 400 Recorder Speed 10 mm/cm Scan Speed 7 Imm

NOTE: Both recorder speed and acan speed will be set automatically by going into wavelength program.

3. Dependent upon site background concentration.

The technique entails acquisition of a headspace sample from a field sample that has been allowed to reach equilibrium. The gaseous sample then is injected with inert gas into a Photovac model 10A10 portable gas chromatograph. The associated individual component concentrations are determined with a simple calculation, using a previous calibration factor based on standard solutions and the measured instrument response for each sample. The instrument operating conditions are shown in Table 1.

METHOD DEVELOPMENT PROCEDURES

Before implementation in the field, optimum operating conditions and procedures were determined for each screening technique. In addition, each method was validated by determining the recovery fraction from spiked samples and establishing positive correlations between the screening technique and standard laboratory analysis.

PNA Screening Method Development

Initially, three target PNA compounds were chosen for both the soil and water method validation. The compounds chosen were the most predominant PNAs at the two sites used to test this technique. These compounds (naphthalene, acenapthene and phanthrene) also should parallel the behavior of the other PNAs known to be present on two test sites. Using standard solutions of the three target compounds, UV fluorescence spectra were generated over a wide concentration range. The fluorescence data were used to determine instrument sensitivity and excitation and emission maxima for the target compounds. This information then was used to determine optimum sample size, method detection limits and instrument conditions for both the soil and water methods. Based on the UV fluorescence characteristics of the target compounds and knowledge of other PNA compounds known to be prevalent on the sites, 280/340 and 250/400 were chosen as the optimum wavelength pairs (excitation/emission) for detection of total PNAs.

A quantitative fluorescence response was observed for each target compound from 0.01 to $1.0 \ \mu g/l$ concentration in the standard solution. The calibration curve was observed to be almost linear within one order of magnitude of concentration. The most accurate quantification was obtained by working within a concentration range of 0.1 to $1.0 \ \mu g/l$.

In the final step of the method development for each site, appropriate extraction solvents were chosen for each method based on performance (i.e., rapid dispersion in soil), sensitivity and lack of instrument interference. Acetonitrile was chosen for the soil/sediment extraction and hexane for the water extraction. The method for screening soil samples consists of adding anhydrous sodium sulfate (to absorb water from wet soil) and UV grade acetonitrile to a weighed amount of soil. The mixture is shaken vigorously for about 15 sec; after 1 min, it can be filtered. The extract then is analyzed by the UV fluorescence spectrophotometer, diluting the extract into a readable range as necessary. For water samples, a measured volume of sample is mixed with UV grade hexane for about 1 min. After 5 min, the hexane layer can be removed and analyzed by UV fluorescence.

Background soil and water samples taken from each of the two sites were spiked with the three target PNAs to establish the accuracy and precision for both the soil and the water methods. The methods showed high recoveries of the PNAs as listed in Table 2. Recoveries above 100% occur because calibration curves were extrapolated to non-linear response regions, thus giving concentrations that were biased on the high end of the scale.

After establishing method performance, soil and water samples from the site were analyzed by the UV screening method. The results were compared to those obtained by U.S. EPA CLP GC/ MS techniques. Standard solutions of the seven most prevalent PNAs previously discussed were used to generate the calibration curve. The PNA screening technique correlated within an order of magnitude of the GC/MS results (Table 3).

Volatile Organics Method Development

Initially, five volatile aromatic compounds were selected for study: 1,1-dichloroethane, 1,1-dichloroethylene (DCE), 1,1,1-trichloroethane, 1,1,2-trichloroethylene (TCE) and 1,1,2,2-tetrachloroethylene (PCE). To demonstrate correlation of the data, laboratory grade water was fortified with a methanolic solution of the above compounds spanning the concentration range of 0-20 µg/l. These solutions were analyzed in triplicate using both the Photovac and standard laboratory methods (purge and trap— U.S. EPA method 601). Blanks containing methanol equivalent to the volume of spike added also were analyzed in triplicate. Additionally, method detection limits (MDL) for specified compounds were determined from data obtained from the Photovac Model 10A10. The instrument parameters used during calibration procedures for the purge and trap system and the Photovac 10A10 are shown in Table 4.

The results showed good response for samples greater than 1 to $2\mu g/l$ of the chloroethylenes (i.e., 1,1,2-trichloroethylene). However, samples of the chloroalkanes (i.e., 1,1,1-trichloroethane) did not exhibit a measureable response at 1000 $\mu g/l$, and the corresponding alkanes could not be identified. This result can be expected because of the high ionization potential, which means these compounds are less likely to be ionized by the Photovac ultraviolet light. These results are presented in Table 5.

In the second step of the method development, standard calibration procedures were identified to demonstrate that the measurement of the standard is not affected by method or matrix interferences. Calibration standards were prepared at a minimum of three concentration levels for each parameter by the addition of secondary dilution standards to reagent water.

Table 2
Method Accuracy and Precision for PNA Screening Technique
for Two Sites

Soil/Sediment Matrix					
Total Concentration µg/g or µg/l ¹	Average Récovery (%) Napthalene/ Acenapthene	RSD (1) ²	Average Recovery (%) Phenanthrene	RSD (¹) ²	
6	85	2.5	87	2.0	
15	63	1.8	77	1.3	
30	79	3.3	78	3.0	
150	90	0.6	85	0.7	
300	92	0.0	89	0.6	
3	65.5	12.7	86.1	9.6	
15	79.0	6.5	92.6	13.0	
30	68.6	3.3	66.4	7.7	
150	100.0	5.5	130.0	9.6	
300	93.2	2.3	94.2	0.9	
<u>Water Matrix</u>					
9	94	10	100	11	
90	98	4.1	97	2.4	
1800	101	4.5	101	3.5	
9	81.0	1.7	92.6	0.8	
90	96.7	1.2	111.0	0.6	
1800	94.0	3.9	96.4	3.6	

1. $\mu g/l =$ Soil matrix concentration; $\mu g/l =$ water matrix concentration.

2. RSD = Relative Standard Deviation.

Table 3
Comparison of UV Fluorescence Screening and GC/MS Data for
Total PNA Concentration in Soil, Sediment, and Water Samples from
Two Sites

Soil/Sedime:	nt Matrix					
Sample I.D.	Sample		10C	uorescence	ation, Bg/4 or	14/1 ⁻
	.,,,-	<u>81</u>	(2	#3	Avg.	OC/HS
851	On-site	16.4	6.5	1.4	8.1	7.0
852	On-site	21.6	45.5	60.8	42.4	120
SS 3	On-site	104,000	76,300	85,700	88,300	19,600
\$\$4	Background	4.1	4.2	3.6	4.0	4.1
9G-1	On-site	490,000	420,000	370.000	390,000	64,000
5G-2	On-site	230,000	230,000	\$2,000	19.000	19,000
BS-1	Background	38	- 48	51	46	35 \
BS-2	Background	4.2	9.5	5.4	6.4	19
Water Matr	<u>ix</u>					
5W-1	On-site	3.1	4.4	6.3	4.6	0.7
6W-1	On-site (2nd site)	4,800	2,600	440	2,600	1,200
SW-2	On-site	490,000	310,000	390,000	400.000	150.000
BW-1	Background	15	17	24	19	10 ²
8W-2	Background	23	27	143	64	102

1. $\mu g/l =$ Soil matrix concentration; $\mu g/l =$ water matrix concentration.

2. ND = Not Detected.

Table 4 Instrument Parameters for the Volatile Organics Method Development

PURGE AND TRAP

Tekmar liquid Sample Concentrator LSC-2 Tekmar Model ALS Automatic Laboratory Sampler Hewlett Packard Model 5880A Gas Chromatograph Tracor Model 700A Hall Elec, Cond. Detector

Carrier: He @ 40 ml./min.

Analytical Column: 8' x 1/8" SS 1% SP 1000 on Cabopack B 60/80 mesh.

Volumne Purged: 5 ml.

Temperature: 45° for 3 minutes

Program: 8⁰ per minute to 220⁰ Rold at 220⁰ for 35 minutes

Intergrator: Hewlett Packard Model 3390A

PHOTOVAC 10A10

Carrier: He at 20 ml./min. Temperature: Ambient approximately (15-24⁰C) Injection Volume: 100 ul Teflon Analytical Column: 1.5' SE-30 Support and & Coating unknown Integrator: Hewlett Packard Model 3390A

Table 5 Method Accuracy and Precision for Volatile Organics Screening Technique

. . .

Parameter	Concentration (ug/1)	Concentration ^L (ug/1)	Concentration (sg/l)	340 (1) ²	Becovery (1
1,1-Dichiorosthylens	2 87 15	2.6	1.65-2.30 6.0 6.24-0.31	18.4 13.8	75
1,1,2-Trichlorosthylene	2'I 0'I 15	2.2 17.3	1.83-3.44 3.1 11,71-18.7	14.5 14.0	
1,1,2,2-Tetrachloroethylene	2 11 15	2.4 24.1	1,42-1,96 3,2 11,10-15,70	9.4 17.0	40

1. 2 hour equilibrium.

2. RSD = Relative Standard Deviation.

Table 6 Performance Audit Samples for Volatile Organics Screening Technique

Sample I.D.	Composind	Reported Value (ue/1)	True Velue (ug/l)	Performance Praimetion
SCF-1	1,1-DCE TCE PCE Onknown	42 1.7 3.7 8.3 Am PCB	## ## ##	Acceptable Acceptable
BC7-1	Ghluova 1,1-DCR TCB PCR	25 as 1,1-DCB 2.1 3.5 13.4	60 7.3 28	Acceptable Acceptable Acceptable

1. Not Present.

2. Unknown VOC is possibly trans-1,2-DCE.

Table 7 Estimated Cost Breakdown for Field Implementation'

PNA Screening	Cost
Analytical facilities (UV fluorescence spectrophotometer, recorder, analytical balance, refrigerator, lab trailer etc.)	\$800 \$900/ wee k
Disposable equipment	\$7-8/sample
Manpower (2 operators)	\$600-\$700/day
Throughput	20-30 samples/day
Estimated average cost per sample	\$40-50.
Volatile Organics Screening	
Analytical facilities (photovac, recorder, lab trailer, etc).	\$600-\$700/day
Disposable equipment	\$2-3/sample
Manpower	\$400-\$500/day
Throughput	20 samples/day
Estimated average cost per sample	\$25-35.

1. Based on 1985 dollars and actual field experience

The field laboratory met the minimum requirements of the U.S. EPA Quality Control Office which included an initial demonstration of laboratory capability and an on-going analysis of spiked samples to evaluate and document data quality. The field laboratory demonstrated through the analyses of quality control check standards that the operation of the measurement system was under control.

To establish the ability to generate acceptable accuracy and precision, two performance evaluation samples were provided by the U.S. EPA. These samples were tested in accordance with the field screening procedure developed for volatile organics during the first week of field screening. A review of the data by the Region V Quality Assurance Office concurred that quantification of trichloroethylene and tetrachloroethylene was acceptable using the volatile organics screening technique. These data are shown in Table 6.

EQUIPMENT REQUIREMENTS AND TYPICAL COSTS FOR IMPLEMENTATION

The cost to implement the PNA screening technique in the field involves equipment, temporary laboratory facilities and operator salaries. The equipment requirements include a UV fluorescence spectrophotometer/chart recorder, analytical balance, disposable laboratory supplies for the extraction process and a small refrigerator to preserve standards.

The average expected cost per sample is \$40-\$50 per sample with a sample throughput of about 20-30 samples per day. The estimated costs are shown in Table 7.

Volatile organics screening in the field involves equipment, temporary laboratory and operator salaries. The equipment requirements include a Photovac instrument with a chart recorder and appropriated disposable laboratory supplies. The estimated cost is \$20-\$30 per sample with a sample throughput of about 20 samples/day. The estimated costs are shown in Table 7.

The PNA and volatile organics screening techniques can contribute valuable information to field programs. However, there are limitations associated with the screening techniques. Because both techniques are actually laboratory procedures modified for use in the field, the limitations for the procedures are similar and can be associated with almost any laboratory procedure.

Both the UV fluorescence spectrophotometer and the gas chromatograph operate at ambient temperature and should be set up in an area in the field where temperatures are expected to remain fairly constant. Therefore, the laboratory trailer should be equipped with an air conditioning and/or a heating unit.

The PNA screening technique is relatively simple; a trained technician can perform the analyses. The operator must have some experience in laboratory extraction procedures, instrument operation and basic instrument properties and screening theory so that any problems encountered during field implementation can be evaluated and corrected.

In addition, an analytical trailer equipped with a fume hood is required for the PNA screening technique because solvents are used in the extraction process. Since the PNA screening technique requires a selection of target compounds and understanding of matrix interferences, it must be validated for each site specific situation.

The volatile organics screening technique requires a qualified chemist with previous GC experience. An additional limitation encountered using the Photovac screening is the requirement of gaseous samples; therefore, headspace samples of a water matrix need to be prepared for analysis. The volatile organics screening has not been developed to screen soil samples.

CONCLUSION

The PNA screening method provides an order-of-magnitude estimate of total PNA concentration in soils, water and sediments. This determination allows the sampling effort to concentrate on and fully characterize contaminated areas and then focus off-site laboratory analyses on the most critical areas. The screening method is site-specific and should not be applied to other site investigations without laboratory investigation to provide recalibration and method validation.

The volatile organic screening technique can be used to determine concentrations of DCE, TCE and PCE compounds in water using head space analysis. In the past, both methods have been successfully implemented for on-site analysis. The volatile organics screening technique was used to analyze groundwater samples to evaluate the vertical stratification of contaminants in municipal wells at an NPL site. The PNA screening technique was used to identify zones of contamination at an inactive wood treating site and will be implemented at an active wood treating site in the near future. Soil, sediment and water samples were analyzed during an on-site investigation; the data were used to make field decisions such as monitor well and test pit placement, and sample selection for off-site laboratory analysis.

Overall, these field screening techniques have been reliable, fast and cost-effective when used within their limitations and in concert with proper laboratory techniques and quality assurance/ quality control procedures.

Statistical Modeling of Geophysical Data

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ABSTRACT

Complex surface geophysical data sometimes cannot be evaluated completely using traditional graphical interpretation techniques. In these cases, statistical models can be useful for restructuring the data set to identify trends not obvious in the raw data. This approach was used to interpret magnetometry, metal detection and electromagnetic conductivity data from the Kane and Lombard site in Baltimore, Maryland.

INTRODUCTION

Surface geophysical surveys are used frequently at hazardous waste sites to identify the locations of buried wastes, leachate plumes and subsurface geologic features. In many cases, evaluating geophysical data is straightforward using traditional graphical interpretation techniques. Occasionally, however, the data are too complex to interpret visually, particularly when complimentary geophysical techniques are utilized. Statistical techniques often can be used in these situations to filter and restructure the data set to provide an evaluation of what might otherwise appear to be unrelatable data. The objective of this paper is to describe a case in which statistical models were used to evaluate complex geophysical data from a hazardous waste site.

SITE DESCRIPTION AND HISTORY

The Kane and Lombard site is an 8.3 acre parcel of undeveloped land located in the southeast quarter of Baltimore, Maryland, southwest of the intersection of Kane and Lombard Streets. It is directly adjacent to Lombard Street on the north, Patterson High School on the east and south boundaries and is within onequarter mile of Baltimore City Hospital and numerous residential properties.

Between 1922 and 1938, the site was graded and flattened, probably in conjunction with the construction of the hospital. Differences in topography between 1922 and 1968 indicate that approximately 10 ft of fill was distributed on the site after 1922. Between 1938 and 1966, two major areas adjacent to the Kane and Lombard site were excavated and may have been used for hazardous waste disposal, given that drums have been observed in the fill.

The period between 1966 and 1971 involved further excavations and the construction of Lombard Street and I-95. This period is especially significant because it included the excavation and refilling of roughly two-thirds of the Kane and Lombard site. If wastes were buried at the site, the burial probably occurred between 1969 and 1971, possibly in conjunction with the construction of East Lombard Street.' From 1971 to 1984, the Kane and Lombard site was used for the unauthorized disposal of construction debris, household refuse and hazardous wastes. In November 1980, inspectors from the Maryland Department of Health and Mental Hygiene discovered drums at the property. The majority of the drums were rusted through or punctured. Air monitoring near the center of the site recorded organic vapors between 10 and 250 ppm on an HNu. At the request of the state, the U.S. EPA conducted an immediate removal of 1,163 exposed drums in April 1984.

SITE GEOLOGY

The site is located on gently-dripping unconsolidated coastal plain deposits of the Potomac Group. The most prevalent of these deposits at the site is the Arundel Formation. The Arundel clay facies is a poorly bedded to massive kaolinitic and illitic clay with local lenses and pods of quartz sand and silt.^{2, 3} The clay is typically gray, brown, black or red with occasional color mottling and is up to 30 ft thick. The Arundel sand facies typically is found within the Arundel clay and is characterized by deposits of wellsorted, medium-to-fine quartz sand interspersed with clay-silt laminae and very thin clay beds. The Arundel sand facies can be up to 10 ft thick. Borings drilled at the site in 1971 and 1982 suggest that the upper 20 ft of material consists primarily of fill and generally stiff, brown, red-brown and black silty-to-sandy clay. Highly variable sand deposits found between 17 and 27 ft below grade in the northeastern portion of the site probably are derived from the Arundel Formation. Across the rest of the site and below 27 ft deep in the northeastern portion, the deposits appear to be primarily gray to reddish-brown clay of the Arundel Formation.

GEOPHYSICAL SURVEY

The geophysical survey of the Kane & Lombard site was conducted in October 1985. The objective of the survey was to gather information on the nature of the materials on the site and identify areas where wastes may be buried. The survey consisted of establishing a 100-ft by 50-ft grid on the site and using electromagnetic terrain conductivity (EM), metal detection (MD), magnetometry (Mag) and ground penetrating radar (GPR) to scan the grid. The results of the GPR survey are not included in this presentation, but are summarized elsewhere.⁴

To compensate for diurnal and other variations and to assist in equipment calibration, two base stations were established and monitored. The primary base station was located in the wooded area on the southeast border of the site. Measurements of EM, MD and Mag were taken at the primary base station at the be ginning and end of each survey day and approximately every 2 hr during the surveys. The secondary base station was located in the baseball field east of the site between the site and Kane Street. Measurements were taken at the secondary base station approx-

imately every 4 hr.

Electromagnetic Conductivity Survey

The EM survey was conducted along the 50-ft by 100-ft grid using a Geonics EM 34-3 terrain conductivity meter. In general, EM measures the electrical conductivity of materials in micromhos over a range of depths determined by the spacing and orientation of the transmitter and receiver coils, and the nature of the earth materials.

Four different EM measurements were made at each grid node by using coil spacings of 10 (33 ft) and 20 m (65 ft) and holding the coils parallel to the ground (vertical dipoles) or perpendicular to the ground (horizontal dipoles). Vertical dipole conductivity measurements emphasize deeper earth materials relative to horizontal dipole measurements which emphasize near-surface materials. The relative depth of response also is directly related to the distance between the coils. Thus, typical exploration depths for 10- and 20-m coil separations would be 25 and 50 ft for horizontal dipoles and 50 and 100 ft for vertical dipoles. However, while both horizontal and vertical dipoles can be used to measure conductivity over the same depth by using different coil spacings, the relative response at different depths is quite different.

Magnetometry Survey

The magnetometry survey was conducted using a Scintrix MF 2-100 portable fluxgate magnetometer. In general, magnetometers measure the intensity of the earth's magnetic field and local magnetic anomalies. By filtering out the earth's magnetic field and nulling the instrument to zero, the local magnetic anomalies caused by concentrations of metallic objects can be quantified. Under ideal conditions, deposits of ferrous metal, such as drums and scrap iron, can be detected up to 60 ft deep using magnetometry.

Metal Detection Survey

The metal detection survey was conducted using a Garrett ADS-6 metal detector with BloodhoundTM attachment. Metal detection measurements were recorded as either "0" (no response), "1" (weak response) or "2" (strong response). In general, metal detectors will respond to deposits of both ferrous and nonferrous metals up to 10 to 20 ft deep.

DATA EVALUATION METHODS

The data from the geophysical survey were evaluated in both raw and statistically filtered forms. The first step in the analysis was to enter the data onto our mainframe computer system and verify the entries. The four types of EM measurements, the Mag readings and the MD data were then each plotted and contoured using the CPS-1 software package. The resulting maps were evaluated individually and together, however, they did not reveal any easily discernible trends or unambiguous anomalies. Trends and anomalies that were detected by one geophysical technique were not confirmed by the complementary techniques.

Factor Analysis

To enhance the interpretation of the trends and anomalies observed, the data from the EM, Mag and MD surveys were statistically filtered using a procedure known as "factor analysis." In factor analysis, variables such as the EM, Mag and MD measurements) are combined statistically to produce a smaller number of new variables called "factors" that account for nearly the same proportion of variance. Scores for the factors then are calculated and analyzed in the same manner as the original variables. These scores will have a mean of zero and a standard deviation of one, thus standardizing the units of measurement and simplifying subsequent computer calculations.⁵ The factor analysis of the EM, Mag and MD data was calculated using the principal components option in the FACTOR procedure of the SAS '82, Version 4 computer software package. Four factors were identified in the analysis, representing deep EM (a composite of the vertical dipole measurements), shallow EM (a composite of the horizontal dipole measurements), metal detection and magnetometry.

The estimated response of the EM factors with depth is shown in Fig. 1. Fig. 2 to 5 are isometric diagrams of scores on the Deep EM factor, the Shallow EM factor, the metal detection factor and the magnetometry factor, respectively. These diagrams are essentially smoothed versions of the diagrams obtained using the raw data.



Figure 1 Relative Response of Electromagnetic Conductivity Factors with Depth



Figure 2 Isometric Diagram of Scores on the Deep EM Factor (Factor 1)



Figure 3 Isometric Diagram of Scores on the Shallow EM Factor (Factor 2)



Figure 4 Isometric Diagram of Scores on the Metal Detection Factor (Factor 3)



Figure 5 Isometric Diagram of Scores on the Magnetometry Factor (Factor 4)

Cluster Analysis

To assist in identifying trends and anomalies, the factor scores were processed using a statistical procedure known as cluster analysis. In cluster analysis, measurements (such as the factor analysis scores) are grouped according to statistical measures of their interrelatedness.* The cluster analysis of the factor scores was computed using the Ward's-Method option in the CLUSTER procedure of the SAS package. The cluster analysis identified four areas of the site that appear to represent:

- "Background Areas (Cluster 1)"—include geophysical grid nodes primarily in the western and southern portion of the site.
- "Debris" Areas (Cluster 2)—include geophysical grid nodes primarily in the southeast-northwest trending band across the central portion of the site.
- "Waste" Areas (Cluster 3)—include geophysical grid nodes primarily in the northern portion of the site.
- "Anomalous" Area (Cluster 4)—includes only one small area in the northeastern portion of the site.

The locations of these clusters are shown in Fig. 6.



Figure 6 Location of Test Pits Relative to Cluster Analysis Groups

Discriminant Analysis

To interpret the basis for the groupings formed from the cluster analysis, the clusters were evaluated using a procedure known as discriminant analysis. Discriminant analysis is a linear regression technique in which data groupings (e.g., the clustered geophysical grid nodes) are related to a function of a set of independent variables (e.g., the four factors that were derived from the six original geophysical measurements). The functions then are assessed to help interpret the underlying nature of the data clusters. The discriminant analysis of the grid node clusters with the geophysical factors was computed using the DISCRIM and CANDISC procedures of the SAS package. The DISCRIM procedure was used to reassess the clusters to identify any misclassified grid nodes. The CANDISC procedure was used to calculate the three discriminant functions which are:

- DF-1 = 10.97 (Deep EM Factor) 0.44 (Shallow EM Factor) + 0.02 (Metal Detection Factor) ~ 0.15 (Magnetometry Factor)
- DF-2 = 0.62 (Deep EM Factor) ~ 1.20 (Shallow EM Factor) + 0.40 (Metal Detection Factor) + 1.34 (Magnetometry Factor)
- DF-3 = 0.11 (Deep EM Factor) + 0.95 (Shallow EM Factor) + 0.98 (Metal Detection Factor) + 0.31 (Magnetometry Factor)

The first discriminant function (i.e., DF-1) was interpreted to

represent deep (i.e., over 20 ft) stratigraphic or groundwater quality anomalies. This function segregated cluster 4 from the other clusters. The second and third discriminant functions were interpreted to represent aspects of waste disposal. The two functions segregated all four clusters when plotted against each other as shown in Fig. 7.



Figure 7 Bivariate Plot of Discriminant Functions 2 and 3



Figure 8 Contour Plot of Discriminant Function 3



Figure 9 Contour Plot of Discriminant Function 2



Figure 10 Contour Plot of Discriminant Function 1

Discriminant function 3 appears to differentiate parts of the site that have been excavated and filled from those that are natural, as shown in Fig. 8. The trend of the zero contour in Fig. 8 corresponds well with the limits of site excavation as shown in a 1969 aerial photograph.⁵ Discriminate function 2 appears to differentiate between metallic debris (i.e., high positive values for DF-3) and high conductivity debris such as concrete (i.e., high negative values for DF-3), as shown in Fig. 9. The trends in this figure appear to correspond to the materials found in the test pits, as discussed in the next section. Discriminant function 1 appears to follow the general trend of suspected contaminant movement at the site, as shown in Fig. 10.

TEST PIT EXCAVATIONS

To verify the findings of the geophysical survey, 24 test pits were excavated to a depth of approximately 10 ft at the locations shown in Fig. 6. Table 1 summarizes the results of the test pit explorations relative to the statistical analysis.

Based on these results, it appears that areas in Cluster 2 have been excavated and filled with wastes consisting primarily of mixtures of household trash and construction debris (e.g., scrap metal, wood, concrete and brick). Areas in Cluster 3 include the same type of waste as is found in Cluster 2 areas as well as decomposed tanks and drums that may have contained volatile wastes. The majority of test pits excavated in Cluster 1 areas found no evidence of buried wastes, thus supporting the contention that these are undisturbed areas.

Table 1 Results of Test Pit Explorations

Cluster Identification Cluster Description	1 "Background" Area	2 "Debris" Aree	3 "Neste" Aree	4 "Anomalous" Anomaly
Hean Value of Discriminant Function	11			
1 - Deep Conductivity Variate 2 - Matal(+)/Concrete(-) Variate 3 - Buried Waste Variate	-1.34 0.52 -1.18	-1.61 2.21 1.28	-1.46 -2.14 0.55	79.50 0.03 0.07
Number of Test Pite in Cluster Area Test Pit Identification	4 A,C, J,X	10 D,E,F, G,E,I, L,O,P,Y	9 K,N,N, Q,R,S, T,U,V	1 B
Percentage of Test Pit Containing:				
Little or No Dabria Tanke and Druam Scrap Metal Concrete, Brick Nod, Paper Hiscollamous Trash	75 0 25 0 25	0 10 40 70 70	11 44 11 55 44 55	0 0 100 100 100
Organic Vapors (BNu) Range of Readings (ppm) Mathane (Gastach) Range of Readings (ppm)	0	0 5_75	22 50-100 22 125-150	<u> </u>
One Waste Type Two Waste Types More Then Two Waste Types	75 25 0	10 30 60	33 22 44	0 0 100
Moisture Content of Test Pit Soil:				
Met Hoist, Damp Dry	0 50 50	20 70 10	22 44 33	0 6 100

CONCLUSIONS

In situations where surface geophysical techniques display complex and apparently unrelated trends (e.g., Fig. 2 to 5), statistical models can be useful to identify underlying data associations. In a study of the Kane and Lombard site in Baltimore, statistical modeling was used to partition the site into common areas (Fig. 6) and compute new variables that appear to be related to the types of waste disposed (Fig. 8 and 9) and to the site's straijgraphy or groundwater quality (Fig. 10).

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Portable X-Ray Fluorescence as a Screening Tool for Analysis of Heavy Metals in Soils and Mine Wastes

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ABSTRACT

X-ray fluorescence (XRF) has several advantages over atomic absorption and inductively coupled plasma techniques that make it useful for the screening analyses of environmental samples. These advantages are: rapid turnaround time, multi-element analytical capacity, nondestructive analyses, minimal quantity of sample required and cost-effectiveness. Further, a portable XRF instrument has the capability of providing on-site analyses that can be incorporated immediately into the field investigation program. The realization of the potential of a portable XRF device has led to an increase in its use in remedial investigations at hazardous waste sites. In most cases, however, the accuracy and precision of the analyses, along with the method detection limits, have not been well characterized. In this paper, these parameters are established for a variety of soil/tailings matrices, calibration techniques and field situations.

The authors have used a portable XRF analyzer to determine heavy metals concentrations in soils, sediments and mining wastes at three hazardous waste sites in Colorado and Montana. The elements determined using a Columbia Scientific portable XRF analyzer were lead, arsenic, copper, zinc and iron. These three sites represent several potential applications of XRF analyses, including: (1) on-site selection of sample locations necessary for definition of contaminant boundaries, (2) screening of samples for further analyses through the Contract Laboratory Program (CLP) and (3) statistical and geochemical evaluation of the spatial variation of metals concentrations. The requirements and limitations of XRF analyses for each application are evaluated.

The results obtained substantiate the dependence of method detection limits on sample matrix variability and analyte concentration ranges. The accuracy and precision of the analytical technique also depend on the number and type of calibration standards used. These conclusions are demonstrated by statistical evaluation of the results of the calibration for combinations of 5, 10, 15 and 20 standards. The results of both replicate analyses and XRF versus CLP comparisons are presented and are used to determine potential sources of error and their relative magnitudes for the entire procedure. This knowledge can be directly applied to the design of field programs that more effectively meet the accuracy, precision and detection limit requirements of XRF analyses for remedial investigations at hazardous waste sites.

INTRODUCTION

As part of the remedial investigations at three hazardous waste mining sites, screening for heavy metals contamination was performed with the aid of a portable energy dispersive X-ray fluorescence (XRF) analyzer. At Site A in Colorado, definition of a 1,000 mg/kg Pb isopleth using on-site XRF in conjunction with geostatistics was accomplished.¹ In the identification of hotspots and areas requiring further investigation at Site B in Montana, XRF provided a useful and cost-effective method for screening for As, Pb, Cu and Zn. XRF screening also was utilized to select samples for further analysis through the Contract Laboratory Program (CLP). At Site C in Colorado, analyses for Pb, As, Cu, Zn and Fe in split spoon tailings samples provided additional information on the relationships between degree and depth of contamination. In this way, zones of metal accumulation and leached zones of metal depletion could be identified.

The potential use of XRF spectrometry as a screening technique for trace constituents at hazardous waste sites has been demonstrated by several studies.^{2,3} In these cases, however, analyses were performed by dedicated laboratory instruments employing sophisticated computer software. The additional advantage of immediate results has led to an increased interest in portable XRF systems, which necessarily are less sophisticated. The purpose of this study was to outline the techniques essential to the proper use of portable XRF instruments and to evaluate the results obtained in relation to the designed screening use of the method.

XRF THEORY

The fundamental principle of X-ray fluorescence (XRF) or emission spectrometry is the detection and measurement of the X-rays emitted from excited atoms in a sample. The excited state is achieved when the critical binding energy of an electron in a particular shell is exceeded by the energy of the incoming source particle. When this happens, an orbital electron is removed from the shell (the atom is ionized) and another electron from a higher energy shell takes its place. The excess energy released as an X-ray photon during this process is characteristic of the atom from which it was produced. There are, of course, many complications to this simplified discussion of XRF theory, and a vast amount of literature addresses them in detail.⁴⁻⁷

Two general types of emission spectrometers can be used: wavelength dispersive (WD) and energy dispersive (ED). Wavelength dispersive systems normally provide very high resolution (sharp narrow peaks) but, because of the additional diffraction step, they suffer from low efficiency (the energies of the characteristic X-rays are attenuated by the diffraction process). Energy dispersive systems, on the other hand, are highly efficient but have less resolving power. Because ED spectrometers do not require high source energies for excitation (i.e., they are more efficient) and elaborate mechanisms for geometric positioning of the detector, they are more adaptable for use in the field. Several compact ED systems are now available, some with sophisticated software capabilities. The energy dispersive XRF system used in this study was a Columbia Scientific X-MET 840 portable analyzer. The X-MET 840 employs a radioisotope source for sample excitation and a high resolution proportional counter for X-ray detection. For the elements analyzed for in this study (Pb, As, Cu, Zn and Fe), a 100 millicurie source, composed of Cm 244 which emits Pu L X-rays with energy ranging from 12 to 20 KeV, was used. The resolution of the spectrometer, as defined by the full width at half the maximum (fwhm) height of the Mn K alpha peak at 5.9 KeV, is about 0.83 KeV or 14%. Typical laboratory ED instruments are now capable of resolutions of less than 0.15 KeV or 2.5%.

SAMPLE MATRIX EFFECTS

The most important consideration in the measurement of X-ray energy is the influence of sample matrix effects. Matrix effects can either increase or decrease characteristic X-ray intensities and, if not corrected for, can lead to significant accuracy problems. In general, these effects can be divided into either physical or chemical matrix effects.

Physical matrix effects are the result of variations in the physical character of a sample. They may include such parameters as particle size, uniformity, homogeneity and surface condition. For example, consider a sample in which the analyte exists as very fine particles within a matrix composed of much coarser material. If two separate specimens (aliquots) of the sample are ground in such a way that the matrix particles in one are much larger than in the other, then the relative volumes occupied by the analytecontaining particles will be different in each. When measured, a larger amount of the analyte will be exposed to the source X-rays in the specimen containing larger matrix particles, resulting in a higher intensity reading for that specimen.

Chemical matrix effects result from differences in concentrations of interfering elements. These effects appear as either spectral interferences (peak overlaps) or as absorption/enhancement phenomena. Both effects are common in soils contaminated with heavy metals. For example, Fe tends to absorb Cu K X-rays, reducing the intensity measured by the detector. This effect can be corrected if the relationship between Fe absorption and X-ray intensity can be modeled mathematically. Obviously, establishment of all matrix relationships during the time of instrument calibration is critical.

Sample matrix effects can never be fully eliminated. They can become relatively insignificant, however, through proper sample preparation and calibration techniques. The techniques used in this study are addressed more fully in the following section.

METHODOLOGY

Sample Preparation

Samples to be analyzed by XRF (including calibration samples) were placed in aluminum pans, air-dried and mixed as well as possible. A representative portion of each sample (40-100 g) was ground to less than 100 mesh, and a 5-10 g aliquot of the resulting powder was then analyzed with the spectrometer. Sample preparation time averaged between 10 and 15 min/sample. Actual analysis time was 4 min/sample.

By saturating the sample preparation step, analytical variations due to physical matrix effects were minimized. In other words, although the physical characteristics of the samples may have been affecting the intensities of X-rays, correction for these effects was not necessary because they were the same for all samples. Of course this assumption was valid only for samples with identical or at least very similar matrices (e.g., for samples collected from the same site). Although the assumption was reasonable from a theoretical standpoint, in practice it was difficult to test. However, one important aspect, homogeneity of the ground powder, was tested. The results of this determination are evaluated later in this paper.

Calibration

The calibration of the XRF spectrometer was based on previously collected and analyzed samples from each site. These samples were handled with the same procedures outlined above in "Sample Preparation." After digestion with HNO_3/H_2O_2 according to the procedures specified by the CLP, samples were analyzed by either inductively coupled plasma (ICP) or atomic absorption (AA) techniques by different laboratories with CLP procedures. The samples do not represent "true" calibration standards in the sense that the accuracy of the different CLP laboratories was not beyond repute. Nevertheless, the potential calibration error due to the inaccurately known concentrations in the samples was probably much less than the potential matrix effect errors that would result using "true" standards with unknown matrices.

Calibration was accomplished by first measuring the intensities of the characteristic analyte X-rays, then developing a concentration versus net intensity regression curve. The calibrations employed for each element and for each site were essentially mathematical models designed to compensate for sample matrix effects specific to the site. The goal was to optimize the calibration for each analyte by correcting for both spectral overlap and/or element interference, if necessary. Spectral overlap, which occurs when two peaks are not completely resolved, was removed by deconvolution (subtraction of one peak intensity from that of another). Absorption or enhancement of characteristic X-rays due to the presence of interfering elements was handled by multiple linear regression analysis. All of the software necessary for calibration is contained within the instrument.

Table 1 summarizes the results of the calibration obtained for each element at each site. The table provides the number of calibration standards (n), the range of concentrations in the standards, the instrument detection limit (discussed in next section) and the resulting correlation coefficient. In all cases, the calibration was excellent with correlation coefficients typically greater than 0.95.

Table 1 XRF Calibration Parameters

Site	Element	•	Analytical Bange (mg/kg)	SD ¹ (mg/kg)	Correlation Coefficient (R)	10L ³ (ng/kg)
Site A	26	3	0-1,000	30	0.999	120
Site B	Pb	20	0-1,200	97	0.949	75
	As	16	0-1,700	91	0.963	90
	Cu	18	0-2.200	190	0.963	60
	1n	20	0-2,500	267	0.943	30
Site C ²	7 6	20	0-4.800	425	0.955	45
	Å	20	0-250	20	0.963	15
	Cu	20	0-3.900	137	0.991	90
	Za	20	0-5.400	97	0.997	60
	Te.	20	0-180.000	18,200	0.951	140

1 Overall standard deviation (root mean square of the residuals) for the regression

2 Model #5 (20 calibration samples)

3 Instrument detection limit

ANALYTICAL PRECISION

Replicate analyses were performed to determine the analytical precision of the X-MET 840. For each site, a check sample was analyzed at regular intervals throughout the analytical run. The results, shown in Table 2, include both instrumental error and error due to spectrometer drift. The data indicate that replicate precision (as indicated by CV, coefficient of variance or standard deviation divided by the mean) is generally less than $\pm 20\%$ for concentrations approaching the method detection limit. At higher concentrations, however, precision is generally less than $\pm 5\%$.

	Table	2
XRF	Replicate	Precision

Site	Element	n	Mean (mg/kg)	SD (mg/kg)	CV (X)	MDL (mg/kg)
Site A	Pb	93	409	52	12.7	156
Site B	Pb	16	143	32	22.4	96
	As	16	215	33	15.3	99
	Cu	16	846	21	2.5	63
	Zn	16	550	17	3.1	51
c_{1}^{2}	Ph	35	713	14	2.8	62
5110 0	As	35	51	-7	12.9	21
	Cu	35	597	27	4.5	81
	Zn	35	728	20	2.8	60
	Fe	35	13.800	870	6.3	2.610

1 Method detection limit

2 Model #5 (20 calibration samples)

XRF DETECTION LIMITS

The limiting factor for XRF precision is the error associated with the X-ray counting process. This error results from the random nature in which X-rays are emitted from the radioisotope source, excited in the sample and counted by the detector. Thus, the lower limit of detection can be estimated from the standard deviation of the counting statistic. For this study, the instrument detection limit (IDL) of the spectrometer was calculated as three times the standard deviation of the counting statistic. It is important to note that the magnitude of the counting error, and thus the lower limit of detection, is directly related to both the total number of X-rays counted and the number of X-rays due to interference and background. Thus, the IDL varies as a function of both measurement time and sample matrix. For example, as shown in Table 1, the IDL for Pb at each site is 120 mg/kg (Site A), 75 mg/kg (Site B) and 45 mg/kg (Site C).

In a similar manner, the method detection limit (MDL) can be estimated from the replicate precision data (Table 2). As noted above, replicate measurements also include the error due to instrumental drift. A comparison of Table 2 with Table 1 indicates that, in general, MDLs are only slightly higher than IDLs, suggesting that instrumental drift was not a significant source of error for the XRF analyses.



XRF vs. CLP for Pb in Site B Soil Samples

XRF VERSUS TRADITIONAL METHODS: STATISTICAL TESTS ON PAIRED DATA

Following XRF analyses at each site, a selected number of ground specimens were sent to the U.S. EPA's CLP for confirmatory analyses. These samples were analyzed by either ICP or AA methods. The results obtained were then compared to the XRF results in order to evaluate the adequacy of the XRF method.

Figs. 1 through 5 are examples of the scatter diagrams obtained for XRF versus CLP analyses. To better evaluate the degree of fit of the data, statistical parameters were calculated. The results of these analyses are given in Table 3 and include the average relative deviation (d), relative standard deviation (Sd), t and Wilcoxon test statistic and the corresponding two-tailed t-test and Wilcoxon test critical values at the 95% confidence level. Readings below the MDL and significant outliers were not included in the statistical analysis.



The average relative deviation (d) represents the degree of deviation of the data from a one-to-one correlation. For example, as illustrated in Fig. 2, the XRF versus CLP results show a positive deviation of about 25% (dashed line) from perfect agreement (solid diagonal line) for Zn concentrations above approximately 1,000 mg/kg. Such deviations are probably the result of uncorrected matrix effects due to an inadequate number of calibration samples at higher concentrations. Below 1,000 mg/kg, the average relative deviation is 0% (see Table 3 and Fig. 2).



XRF vs. CLP for As in Site B Soil Samples



Figure 5 XRF vs. CLP for Fe in Site C Tailings Samples

The agreement between the XRF and CLP results was evaluated using Student's t-test and Wilcoxon's signed-rank test. The t-test determines whether the means of two normally distributed populations are the same, while the Wilcoxon test determines whether two populations are symmetric (same or similar shapes) and, if symmetric, whether they differ in location. Since normal distributions also are symmetric, the Wilcoxon test is probably the preferred test.⁸ The Wilcoxon test typically is termed a non-parametric or distribution-free test while the t-test is appropriate only for normally distributed data.

Through statistical analyses, it was determined that, for all elements, neither the CLP nor the XRF data were distributed normally. Rather, the populations more closely resembled lognormal symmetric distributions. Further, most element distributions were bimodal. Therefore, the t-test was applied to the logtransformed data, and the Wilcoxon test was applied to the non-

Table 3 X-MET and CLP Comparison

	Taraneter					¥1	leases	Test	4-1	fest
\$ite		Parameter	Bange (ng/hg)	•	4 (X)	M(1)	٧.	٧.	V. 95	,
\$110 8		34 - 3180	45	-15	34	444	371	344	-0.90	2.41
	Cu	64 - 1340 1340 - 4030	26 14	-9 20	26 11	19) 0+	159 136	18 30-	-1.11 4.13e	2.05 2.13=
	n	69 - 1640	33	٠	26	203	350	171	0.11	1.0)
	La	34 - 1000 1000 - 5470	30 18	0 25	33 13	157 04	113 171	137 41•	-0.84 5.44	2.45 7.11-
SI te A	n	54 - 20,000	13	25	63	25	"	v	1.42	2.18
stie c ¹		15 - 2400	31	20	34	105-	391	148=	2.50-	2.80
	44	0 - 1 3 1	31	15	80	211	290	14	1.37	2.44
	C.	0 - 1140	31	-16	122	202	295	148	-1.61	7.M
	2.0	20 - 2290	31	10	-0	143+	354	148+	3.40	7.m
		0 - 150,000	31	2	47	226	270	148	0.17	2.61

1 Model 5 (20 Calibration Samples)

significant difference

transformed data. The results given in Table 3 were evaluated as follows:

- Agreement between the XRF and CLP populations was indicated for values of t between ± t.95. Values of t outside of ± t.95 indicated that the two population means were significantly different at the 95% confidence level.
- Agreement between the XRF and CLP populations was indicated for values of W.95 that fell outside of the critical range of W + and W (or both W + and W must be greater than W.95). For example, from Table 3, a value of W.95 = 171 is given for Site B Pb. Since this value lies outside of the W -203 and W + = 358 range, the means of the two populations do not differ significantly at the 95% confidence level.

As indicated in Table 3 by the asterisk, both statistical tests indicate significant differences in the two methods only for Pb at Site C and Cu and Zn at Site B.

SIGNIFICANCE OF THE NUMBER OF CALIBRATION SAMPLES

To correct for absorption or enhancement interferences, an adequate number of calibration samples must be included in the regression model. The exact requirements will depend on the number of potentially interfering elements, their concentration range(s) and the requirements of the particular investigation. The greater the knowledge about how a sample matrix varies at a particular site, the more sophisticated the calibration model can be and, therefore, the more accurate the results.

To address the significance of the number of calibration samples, five different models were developed for Site C. Each model (1 through 5) covered similar analytical ranges but had pro-

Table 4 Site C Zinc versus Number of Calibration

					VII	coren Te	et	1-	feet
Ande 1	Mamber of Colibration Samples	•	4 (8)	30 (E)	۷.	۲.	¥.95	١	1.95
1	3	31	-10	131	175	มา	148	-1.78	\$.DI
2	10	31	16	44	188	374	148	0.30	3.04
3	15	31	16	74	187	348	148	0.32	3.04
4	20	n	19	ж	101	393	148	1.n	1.0
,	20	n	10	40	142	354	148	1.40	2.0

gressively larger numbers of calibration samples. The results obtained for each model then were compared to the corresponding CLP results. As shown in Table 4, a significant improvement in the comparison for Zn occurred between model 1 (5 calibration samples) and model 2 (10 calibration samples), but the relative improvement became decreasingly less above 10 calibration samples. This same trend was observed for the other Site C elements and indicated that at least 10 calibration samples were necessary to adequately analyze the samples (i.e., to correct for the variation in matrix element concentrations), but more than 10 probably were not necessary.

ANALYSIS OF VARIANCE

The purpose of this section is to address the various sources of error associated with the XRF analytical technique. The magnitude of these errors, as measured by their variances (S²), then can be evaluated for the statistical significance relative to the overall variance of each element (contaminant) within the sample environment. In this way, it is possible to determine whether or not the XRF technique can distinguish between different concentrations of an element within a contaminated area and, therefore, whether the technique is valid for screening analysis.

For this determination, total variance was broken down into three components, as shown by:

 $S^{2}Tot = S^{2}Sample + S^{2}Calib + S^{2}Anal$ (1)

where each variance component was evaluated as follows:

- Sample variance (S² sample) was determined from the concentration distribution of the entire population.
- Calibration variance (S² Calib) was determined from the standard deviation (SD) of the calibration curve (Table 1). This variance included both the error due to uncorrected matrix effects and the error due to the uncertainty in calibration sample concentrations.
- Analytical variance (S² Anal) was determined from the standard deviations of both replicate precision (Table 2) and sample preparation. This variance included instrumental (counting) error, drift error and error due to the nonhomogeneity of the ground specimen.

Homogeneity was determined by analyzing separate aliquots of the ground specimen. The standard deviation obtained from the analysis was of the same order as that obtained for the replicate precision analyses. Therefore, the error due to powder nonhomogeneity was negligible for these samples.

The percentage of the total variance of each component is shown in Table 5; the variance due to the samples (S² Sample) is by far the primary component in all cases. Calibration variance (S² Calib) and analytical variance (S² Anal) are relatively minor. This result indicates that the XRF technique is adequate for distinguishing between different concentrations of the contaminants at the three sites. In other words, the error due to the X-MET calibration and analysis is insignificant relative to the total variance of each element.

CONCLUSIONS

The data presented in this study indicate that the portable X-ray fluorescence technique is suitable for screening As, Pb, Cu, Zn and Fe in soils contaminated with mine wastes. The XRF versus CLP comparisons show no statistically significant differences between the two analytical results for these elements over most concentration ranges. As determined by the components of variance analysis, the errors resulting from the XRF method are minor compared to the sample variance at each of the three sites. This result illustrates the ability of the XRF method to

discriminate	between	different	contaminant	levels	under	the
highly variab	le concen	tration cor	nditions likely	to be e	ncounte	ered
at mining wa	ste sites.					

Table 5 Analysis of Variance								
Percent of Total Variance								
Site	Element	S ² Sample	s ² Calib.	S ² Anal.				
Site A	Pb	100	0	0				
Site B	Pb	90 94	9	1				
	Cu Zn	95 86	4 14	1 1				
Site C ¹	Pb	76	24	0				
	As Cu	64 87	19 12	17				
	Zn Fe	98 99	2 1	0 0				

1 Model 5 (20 Calibration Samples)

The results confirm the importance of obtaining an adequate number of calibration samples in order to model the matrix variations present within the samples. For Site C, at least 10 calibration samples were necessary to correct for sample matrix effects. Although more than 10 samples did further improve the calibration, the degree of improvement was not significant, especially in light of the intended screening use of the XRF technique.

For the three sites discussed in this paper, a total of about 1,000 soil/tailings samples have been analyzed with the X-MET 840 X-ray fluorescence analyzer. These analyses have helped establish heavy metal relationships, including both the spatial extent and relative degree of contamination. The ease of sample preparation and analysis in the field (i.e., rapid turnaround times) has been invaluable for on-site coordination of field sampling activities. Also, selection of more representative sample sets for further CLP characterization has been achieved. These advantages have made XRF screening for heavy metals a very cost-effective means of maximizing the amount of information obtained from a field sampling campaign.

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Field Methods and Mobile Laboratory Scenarios for Screening and Analysis at Hazardous Waste Sites

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ABSTRACT

Field Investigations Teams have developed field sampling and analysis techniques that have effectively assessed field conditions at hazardous waste sites for specific contaminants and data quality objectives to supplement the U.S. EPA Contract Laboratory Program.

Methods and protocols currently used for field screening of volatile organics, semi-volatile organics and metals are discussed. Other methods for Non-HSL parameters (TOC, TOX and RCRA compatibility testing) and their potential for use to support various field screening objectives are discussed.

Three levels of mobile laboratory capability are described and compared to commercially available laboratories.

INTRODUCTION

The purpose of this review is to discuss proven methods for field analysis of environmental samples at hazardous waste sites. Other analytical methods that could complement currently used Field Investigative Team (FIT) procedures are discussed as well. Scenarios utilizing various configurations of methods and instruments in mobile laboratories also are discussed. These topics are presented in greater detail in a comprehensive FIT document entitled "Field Investigation Team Screening Methods and Mobile Laboratories Complementary to Contract Laboratory Program." That FIT document also discusses innovative sampling techniques such as soil-gas sampling and air sampling that are not discussed in this review. The reader is referred to that document for discussions of these sampling techniques and a more thorough discussion of analytical methods for field analysis and screening.

Various U.S. EPA Field Investigation Teams (FITs), contracted to investigate hazardous waste sites, have developed highly effective analysis techniques for screening for certain contaminants. Methods of organic analysis employ gas chromatography (GC). Several brands of GCs have been successfully used by the FIT in the field. Each has different capabilities and degrees of portability; however, the basic functions of all GC instruments used are the same. Table 1 lists some of the major differences of the GCs used by the FITs.* Metals analysis has been accomplished through the use of an x-ray fluorescence (XRF) spectrophotometer. The XRF methods used have the advantages of rapid analysis and small sample volume requirements.

HAZARDOUS SUBSTANCE LIST METHODS

Hazardous substance list (HSL) compounds currently are analyzed in the U.S. EPA Contract Laboratory Program. This list contains over 130 organic compounds, 24 metals and cyanide. Organic HSL compounds are analyzed by gas chromatography/ mass spectrometry (GC/MS) in the CLP laboratories. The mass spectrometer allows confirmation of all HSL compounds, even in very complex samples, i.e., samples with many interfering peaks such as oil wastes.

The organic field analysis methods described in this section and presently used by the FITs use gas chromatography alone. Consequently, mass spectrometric confirmation is not available. A degree of confirmation can be performed in the field by using a second, different GC column. However, this becomes very difficult when analyzing complex samples containing many interfering peaks. In addition, many GCs used in the field lack the resolutional capabilities of more expensive non-portable GCs found in the CLP labs. For these reasons, it is necessary to determine, through prior sample analysis and/or historical information, the expected contaminants that are at a site before this level of field screening is performed. By knowing what to expect at a particular site, specific standards can be prepared and samples can be analyzed for these contaminants of concern. However, the field screening methods also can be used to locate areas containing unknown contamination. These samples can be sent to a CLP lab for complete GC/MS analysis and confirmation. Thus, the field methods currently used by the FITs can be used to either analyze for specific contaminants or to screen sites containing unknown contamination.

Field analysis of metals by x-ray fluorescence does not suffer from the interferences described above for organic analysis. During the XRF analysis, each metal present in the sample fluoresces at a unique wavelength. The XRF instrument is programmed to select the specific wavelengths for each metal of concern. For this reason, prior knowledge of metals contamination is not required.

^{*}Trade names and company names are used for identification only and do not imply endorsement by Ecology and Environment, NUS or the U.S. EPA.

Table	e 1				
Comparison of Gas Chromatographs	Used	by	Field	Investigation	Teams

NAME	OVEN TEMP RANGE	POWER	DETECTION LIMITS*	SPECIAL FEATURES
AID-511	ambient_200°C	battery/115 VAC	1 pg CC14 (ECD), .05 ppm propane (FID)	interchangeable detector modules
				temp. programmable; separate inj/det
Shimadzu Mini-2 & Mini-3	ambient-390°C	115 VAC	.2 pg -BHC (ECD), 0.01 coulomb/g (FID)	temps.; capillary column capability
Photovac Model 10A10	ambient	battery/115 VAC	0.1 ppb benzene (PID)	<u> </u>
HNu model GC-301	ambient-300°C	battery/115 VAC	5 pg benzene (PID), 100 pg benzene (FID)	
			1	
OVA model 128	anbient	battery/115 VAC	0.2 ppm benzene (FID)	very portable

*Manufacturer's specifications

pg = picograms

ppb = parts per billion ppm = parts per million

coulomb = unit of electrical current

In all field analyses, standard quality assurance/quality control (QA/QC) is employed. This procedure includes use of appropriate standards to calibrate instruments in the expected operating range. Method blanks are used to check for laboratory contamination and cross contamination of samples. At least 10% of all samples within each matrix type (soil, water or air) should be spiked with the compounds of interest and also run in duplicate to document the accuracy and precision of the method. A complete discussion of QA/QC procedures used by the FITs is in the aforementioned FIT document.¹

Volatile Organics in Soil and Water

Samples are collected in 40 ml septum vials and analyzed by the head space technique. If CLP confirmation of positive results is desired, duplicate vials should be filled when sampling. In this way, identical samples can be sent to the CLP for confirmatory analysis without resampling. Water samples can be collected leaving approximately 25% head space, or the vials may be completely filled and a syringe inserted through the septum to withdraw exactly 25% of the total volume.

Soil samples are weighed and carbon-free water is added to leave a 5 ml head space. After sonication for 1 hr, the sample is analyzed on a "wet weight" basis.

Volatile Organics in Air

Air samples can be collected as grab samples in sampling bags or as composite samples using adsorbents. The FIT has used activated carbon and Tenax[®] adsorbents successfully to collect composite samples. Prior knowledge of the type of contaminant is helpful when choosing the particular adsorbent to use. Each has different characteristics and is best suited for specific kinds of compounds.

Grab samples can be analyzed by direct injection using a gastight syringe. Composite samples can be thermally desorbed using a desorption unit in the field (Century Programmed Thermal Desorber Model PTD-132A, or equivalent) followed by GC analysis. Adsorbents can be used to concentrate the contaminants of concern allowing for increased sensitivity and lower detection limits.

Acid, Base/Neutral Organics in Soil and Water

Field analysis for semi-volatile organic compounds requires gas chromatographs capable of maintaining an oven temperature above ambient temperature. This requirement precludes the use of several of the GCs listed for volatile analysis. The FIT has successfully used the AID-511, Shimadzu Mini-2 and Mini-3 and the HNu GC-301 for semi-volatile analysis.

Thus far, field analysis of semi-volatile compounds in water and soil has been limited mainly to polycyclic aromatic hydrocarbons (PAHs). The sample preparation and analysis is based on modifications to EPA Method 610. The PAHs are extracted into methylene chloride by mixing followed by a silica gel column cleanup to remove potential interferences. The lower limit detection for PAHs is between 50-500 mg/kg for soils depending on the particular compound of interest.

Pesticides/PCBs in Soil and Water

The Electron Capture Detector (ECD) has provided a very selective technique for field GC analysis of pesticides/PCBs. The FIT has found the AID-511 and Shimadzu GCs to be very satisfactory for this purpose.

The field analysis method for pesticides/PCBs in soil requires a hexane extraction and subsequent GC-ECD analysis. The detection limit for pesticides in soil is approximately $20 \mu g/kg$.

Pesticides/PCBs analysis in water samples requires a liquidliquid hexane extraction followed by GC-ECD analysis. The detection limits for pesticides and PCBs in water are 100 μ g/l and 200 μ g/l respectively.

Metals in Soil and Water

Field analysis has been performed using the Kevex 7000 x-ray fluorescence (XRF) spectrophotometer for the following elements: chromium, barium, cobalt, silver, arsenic, antimony, selenium, thallium, mercury, tin, cadmium and lead.

Due to fundamental limitations of the XRF technique, it is not possible to analyze for beryllium and boron. Aluminum is not analyzed due to low instrument sensitivity to this element.

Simultaneous detection of all elements analyzed is one of the greatest advantages of XRF. X-ray fluorescence also has the advantage of being sample-conservative. Atomic absorption (AA) and Inductively Coupled Argon Plasma (ICAP) require destruction of the sample for analysis, whereas the XRF sample remains virtually unchanged and can be stored for future reference. Samples of almost any medium can be run, and only a very small quantity (one gram of soil or 50 ml of water) is needed. Sample preparation can be used to preconcentrate the sample to decrease detection limits. This procedure requires a greater quantity of sample, but such preparation is seldom necessary. The detection limits will vary for each metal; for example, the detection limit for lead is approximately 75 μ g/l in water and 20 mg/kg in soil.

NON-HSL PARAMETERS

Non-HSL parameters are not included in the regular CLP protocol and are not currently used by the FIT. They are presented to suggest alternatives to CLP analysis for specific applications. Two groups of tests for non-HSL parameters are discussed here. The first group consists of tests required by RCRA for classification of wastes as hazardous or non-hazardous. The second group consists of tests that may be used for certain samples for rapid non-specific screening to locate areas suspected of containing hazardous wastes.

RCRA-Related Methods

Sampling inspections at hazardous waste sites sometimes generate potentially hazardous waste, usually from drill cuttings and water from monitoring well installation. Such wastes are governed by RCRA regulations and must be handled accordingly. Due to the scarcity of approved RCRA disposal facilities for hazardous wastes, such wastes often remain in sealed containers on-site until an approved facility can be located. Non-hazardous wastes do not require special handling and may be disposed of in a typical manner. Therefore, the ability to determine whether or not a waste is hazardous through rapid analysis would be a valuable tool.

The tests required by RCRA to determine the hazardous nature of non-specified (in Appendix VIII) wastes are ignitability, corrosivity, reactivity and EP toxicity. In addition, wastes must be analyzed for PCBs and dioxin. The feasibility of performing each of these tests in the field is discussed in the FIT document.' These procedures are not modified for field screening (with the exception of PCBs) and therefore would require the support of a fairly sophisticated mobile laboratory.

Non-Specific Screening Methods

Two useful non-specific screening methods are Total Organic Carbon (TOC) and Total Organic Halides (TOX). These tests do not identify specific organic compounds; however, when used in conjunction with other analytical procedures (GC and XRF), they may aid in rapid site characterization.

Because soils (and some waters) have a large amount of natural organic carbon, the usefulness of TOC may be limited and care must be used in interpreting these data. In contrast, TOX only measures the organically bound halides (chlorine, bromine and iodine) in the sample, and the background concentrations of these are much lower. Therefore, TOX could be used to rapidly locate areas containing PCBs, chlorinated pesticides and chlorinated solvents. Once a suspected area was located using TOX results, GC analysis could be used to identify and quantitate specific contaminants.

LABORATORY SCENARIOS

Field analysis can be performed through a variety of approaches depending on the data quality objectives of the sampling mission. In this study, three levels of mobile laboratory capability are presented based on various data quality objectives. Cost estimates for procuring and operating government-owned, contractor-operated mobile laboratories also are provided. A limited comparison between these cost estimates and three contractor bids for a medium-level (Level 2) scenario was conducted. Implementation of a mobile laboratory operation would require a more thorough analysis of the cost implications and economic feasibility; however, the costs and economic evaluations presented are considered acceptable for planning and budgetary purposes.

Cost estimates in this study are based on assumptions concerning variables such as analysis time. Assumptions used for cost estimates for each scenario are presented in conjunction with the

Level 1

The highest-level data quality objective considered here is CLP. level data. These data would be obtained using identical protocols as used in the CLP laboratories and would provide the same level of quality. These field data would require neither confirmation by a CLP laboratory nor prior knowledge of site contaminants. However, it is good QA/QC procedure for any laboratory to cross-check results periodically with other laboratories.

U.S. EPA methodologies would be used, and U.S. EPA QA/ QC protocols for CLP data would be implemented. However, this level of quality would prevent immediate reporting of results. The effort required to comply with current CLP protocols would require at least a 1- to 5-day analysis time between sample collection and data results. Depending on the complexity and number of samples, this lag time could increase substantially. As an estimate, an analysis rate of six samples/day is projected. This rate assumes that the laboratory is operated for two 8-hr shifts per day. This rate is based on an average and is more accurately defined as 30 samples/week. In other words, after the laboratory is set up and functioning, if 30 samples were received on the first day, the results could be provided by the fifth day.

The equipment required for a Level 1 mobile laboratory is identical to that required for a typical CLP laboratory. To meet the typical litigation requirements of the U.S. EPA, no modification of the methods or the contract statement of work would be acceptable. Table 2 lists the major instruments needed and their approximate costs. This list is presented as a general guide, and the prices listed are estimates only.

 Table 2

 Costs of Major Equipment for Mobile Laboratories

	N	pproximate Cost	(\$)
Equipment	Level	Level Z	Level 3
CC/NS, data system purge and trap (volatile organics), and DC/NS, data system auto-sampler (semi-volatiles)	350,000	NA	
GC/lon Trap Detector, data system (volatile organics), and GC/lon Trap Detector, data system (semi-volatile analysis)	84	150,000	
GC-ECD (auto-sampler pesticides/PCRs)*	40,000	35,000	9,000
GC-F1D (screening)*	25,000	10,000	
2 GC-FID (volatile à sani-volatile organics)		MÅ.	14,000
ICAP (metals)	100,000	M	84
AAS-graphile furnace	50,000	MA	
X-Ray Fluorometer*	**	30,000	20,000
TOC enalyzer (screening for total organic concentration)	20,000	**	
TOX analyzer (screening for halogenated compounds)	15,000	**	
Fune hood (organic extraction)	9,000	9,000	8 1
Fune hood (metals digestions)	9,000	NA	
Analytical balance	3,000	1,000	1,000
Nuffle furnace (KON fusion of high- hazard samples)	1,000	M	
Drying oven	1,000	M	
Slove box	5,000	**	
Glassware, solvents, supplies, etc.	50,000	15,000	10,000
TOTALS	\$678,000	\$250,000	\$54,000

*Differences in price reflect varying degrees of capability to meet data quality objectives.

The recommended vehicle for the Level 1 scenario would be a specially designed and modified 40-ft semi-truck trailer which would require a certified contract driver and semi-type truck to transport it to and from each site. Ideally, the trailer would be divided into three sections. One section would be used for receiving and preparing samples for analysis. This area would contain the fume hoods, balance, drying oven, glove box, muffle furnace, sinks and bench space necessary for sample preparation. The second section would be equipped for organic analysis. This section would contain the two GC/MS systems, GC-ECD, GC-FID, TOC analyzer and TOX analyzer. The third section would contain the ICAP and AAS-graphite furnace for metals analysis. The two instrument sections (organic and inorganic) should be equipped with air conditioning and heating systems that provide a positive air flow to help prevent cross-contamination. They also should have sufficient capacity to replace the air vented through the fume hoods during sample preparations. This helps maintain a constant temperature in the laboratory.

To provide electrical power in remote locations, the Level 1 mobile laboratory should include two generators. One would be used to provide a high-quality power supply for the instruments. The other generator would be used to run the lights, heating and air conditioning systems, exhaust fans in the fume hoods, extraction equipment and smaller equipment used in the laboratory. Since the required generators would be quite large, a separate trailer for these should be considered. The laboratory also should have the capability to accept power from conventional sources when available.

A reliable source of water would be required for analysis. A central reservoir could supply tap water, and a deionization system also would be included to supply reagent-grade water. For carbon-free water needed in trace organic analysis, a high-intensity ultraviolet light/peroxide system could be used.

The vehicle would be fitted with benches specially equipped with racks and fasteners to secure all equipment stored in the laboratory. All gases needed for the analytical instruments would be stored in a centrally located area with easy access for replacing cylinders. Gas lines would run from this area behind the benches directly to the instruments to minimize clutter. In general, careful planning would be required to insure that all space was used in the most efficient and safe manner possible.

Considering the extreme sensitivity of the instrumentation in the Level 1 mobile laboratory, the need for a specially designed suspension system is extremely important. The effectiveness of this system in reducing the level of vibration during mobilization is essential to meeting the projected analysis rate and maintenance schedules of the major instruments.

The estimated purchase cost and modification of the Level 1 mobile laboratory vehicle is between \$300,000 and \$500,000. For the purpose of cost analysis, the \$500,000 figure is used.

Projected costs of acquiring and operating a Level 1 mobile laboratory are discussed below. It must be emphasized that these costs are estimates only. Certain assumptions must be made in order to present these estimates. These assumptions are:

- The useful life of the instrumentation and mobile laboratory vehicle is over a 5-yr period.
- For approximately 3 months per year, the laboratory would be inoperable due to maintenance and calibration requirements.
- A total of 8 days of down time will be required per site for travel, set up, calibration and restocking of supplies.
- A support warehouse would be needed to house the laboratory and provide facilities for maintenance and calibrations. Two support personnel would be required for preparation and ordering of supplies and report preparation.

- Eight chemists would be required to run the laboratory. The cost of personnel includes salaries multiplied by a factor of 2.2 to cover overhead expenses.
- The average rate of analysis would be six samples/day, operating with two shifts.
- Maintenance would average approximately \$1,000/month.
- Expendable items used would average approximately \$2,000/ month.
- The cost of the full HSL analysis by CLP laboratories is assumed to be \$1,350/sample. Approximately 180 days per year would be available for field analysis (9 months at 20 working days per month).

Yearly operating costs for the Level 1 mobile laboratory, operating with two shifts, are shown in Table 3.

Table 3					
Yearly	Operating	Costs	for	Mobile	Laboratories

	Level	Level 2	Level 3
Capital equipment and vehicle	235,600	78,000	24,800
Personnel: [Cost (no. of personnel)]			
Chief chemists	198,000(2)	66,000(1)	66,000(1
Senior chemists	242,000(4)	110,000(2)	NĂ
Junior chemists	88,000(2)	NA	44,000(1
Per Diem, Travel, Lodging	95,360	43,200	28,800
Warehouse:			
Rental cost (\$6.00/sg. ft.)	12,000	6,000	4,500
Utilities (\$2.50/sq. ft.)	5,000	2,500	1,875
Xeroxing Support:	3,000	MA	NA
Support Personnel [Cost (no. of personnel)]	110,000(2)	44,000(1)	NA
Service contracts for major instruments	36,000	5,000	NA
Contract driver with truck	40,000	MA	NA
Lab maintenance	30,000	6,000	6,000
Expendable supplies	36,000	18,000	12,000
Total Yearly Operating Costs	\$1,130,960	\$378,700	\$187.975

Level 2

The second-level data quality objective is approximate CLPlevel qualitative data, but semi-quantitative data which may require confirmation by CLP analysis of a percentage of the samples. Data of this quality may not be litigable, but they are useful and appropriate for water, soil and air sampling during certain field investigations and remedial activities.

Modified CLP methods and protocols would be used, allowing for same-day turnaround of sample results. A conservative estimate of 12 organic and inorganic samples per day for Level 2 analysis is used in this study. This laboratory could analyze low-, medium- and high-concentration samples but would not be equipped to handle high-hazard samples (no glove-box). It would be equipped with mass spectrometers to provide confirmation of organic analysis results.

Table 2 lists the major pieces of equipment and their approximate costs. As in the Level 1 mobile laboratory, a separate GC/Ion Trap × detector system should be used for volatile and semi-volatile (AB/N) analysis. The Ion Trap[®] detector is a relatively new concept in mass spectrometric analysis. It is rugged, compact and relatively inexpensive; other comparable MS equipment also is available commercially. With mass spectrometric confirmation capabilities, prior knowledge of site contaminants would not be necessary. The approach to metals analysis in the Level 2 laboratory is very different from the conventional approach of the Level 1 laboratory. The X-ray Fluorescence (XRF) technique is a rapid, reliable alternative to conventional ICAP or AAS techniques. In addition, its compact size is well suited for the Level 2 laboratory. All analytical instruments would be equipped with automatic injectors and sample handling devices to facilitate introduction of samples for analysis and rapid turn-around of results.

Less space would be needed to house equipment used in the Level 2 mobile laboratory than in the Level 1 laboratory due to the modifications made to the analytical procedures. This reduction is space needs allows the use of a vehicle such as a panel truck or recreational vehicle modified to serve as a mobile laboratory. A contract driver would not be needed to move the laboratory to the site being studied. This would result in simpler logistical requirements and would enable faster mobilization of the laboratory.

The estimated cost of a 35-ft recreational vehicle is between \$65,000 and \$85,000. Modifications to the vehicle would include: installation of a generator(s); heating and air conditioning systems; installation of benches, hood and water system; modification of the vehicle's suspension; installation of gas lines for the GCs; and installation of the instrumentation. The estimated cost of this conversion is between \$45,000 and \$55,000. Using the high end of each estimate, the projected cost of the Level 2 mobile laboratory is \$140,000. Yearly operating costs are summarized in Table 3.

Assumptions used to determine cost estimates and projected cost savings are similar to those presented for Level 1 and are summarized in Tables 2 and 4.

Level 3

The third-level data quality objective is semi-qualitative and semi-quantitative data. A percentage of the samples would have to be confirmed by CLP analysis. Data of this quality may not be litigable but are useful for screening purposes. Modified CLP methods and protocols would be used, resulting in a same-day turn-around of results. This laboratory could provide screening for specific contaminants expected to be present based on previous analyses, but could not provide GC/MS confirmation. For this reason, prior knowledge of site contaminants would be needed to analyze specified compounds. Information indicating complex contaminant mixtures may preclude the use of the Level 3 laboratory. The Level 3 laboratory could analyze low- and medium-concentration samples. Extremely hazardous samples could not be analyzed, and samples with a complex matrix or interfering compounds could not be readily analyzed.

The instruments used in the Level 3 mobile laboratory are designed for basic analysis. Table 2 lists the main instruments.

The two GCs equipped with Flame Ionization Detectors (FIDs) would be used with specific compounds in mind. They should be equipped with temperature programming and dual column capability to allow for some degree of confirmation and analytical flexibility.

The vehicle required for the Level 3 laboratory would be a modified step-van. The modifications would include: an expanded roof to allow for head room; a generator; and wiring to supply power to the instruments (capability to use conventional power supplies would also be included), the heating system and the air conditioning system to maintain the temperature and laboratory benches. The cost of the Level 3 vehicle and its conversion would

	Level	Level	Level
••••••••••••••••••••••••••••••••••••••	1	2	3
Data Quality	litigation quality	confirmed screening (organics)	unconfirmed screening
Mobilization time	pre-planning required	rapid response	rapid response
Capital costs	\$1,178,000	\$390,000	\$124,000
Yearly operating costs	\$1,130,960 (2 shifts)	\$378,700	\$187,975
Down-time/site	8 days	5 days	5 days
Analysis days/year	180 days	200 days	200 days
Analysis rate	6 samples/day (2 shifts)	12 samples/day	12 samples/day (avg.)
Max, samples/year (1)	1032	2340	2340
Cost/sample	\$1,096	\$162	\$80
Max. poss. sites/year (2)	20	33	33
Cost/sample	\$9,425	\$956	\$475

 Table 4

 Summary of the Mobile Laboratory Scenarios

(1) The "maximum number of samples" figure assumes that the mobile laboratory is stationed at the same site for the entire year.

(2) The "maximum possible sites/year: figure assumes that only one analysis day will be spent on-site.

be in the range of \$35,000 to \$45,000.

The van would be too small for sample preparation; therefore, a small 15-ft trailer also would be needed. This trailer would contain benches, exhaust hood, electrical power and a heating and cooling system. These systems would plug into a second generator in the trailer, which also would be used to run the heating and air conditioning system in the mobile laboratory. The cost of the trailer and its conversion would be between \$15,000 and \$25,000. The total cost of the Level 3 mobile laboratory vehicle and conversion would be \$79,000. The yearly operating cost of the Level 3 laboratory is summarized in Table 3.

Assumptions used to arrive at operating costs for the Level 3 mobile laboratory are summarized in Tables 2 and 4.

Lease Versus Buy Analysis

An effort was made to obtain daily leasing rates from companies that offer mobile laboratory services on a contract basis. Price quotes for non-site specific comparative purposes were difficult to obtain. Moreover, not many mobile laboratory contractors have laboratories that were equipped like the Level 1, 2 and 3 systems described above. However, based on limited data (three bidders) for a laboratory comparable to Level 2, the "buy" option appears to offer significant cost and operational benefits over the "lease" option. A government-owned and operated (by U.S. EPA, FIT or other government contractor) laboratory would cost about \$3,800 per day to operate at 50 percent utilization (100 operating days per year). By comparison, three quotes obtained for a Level 2 contractor-operated laboratory were:

- Company A \$6,000/day
- Company B \$3,600/day
- Company C -- \$5,000-\$8,000/day

The spread of quotes reflects several things: uncertainty as to specific requirements, unwillingness of laboratory contractors to provide reliable quotes for study purposes only and the fact that the layout, contents and capabilities of the laboratories varied, even though it was claimed by the bidders that they would be able to meet Level 2 requirements. Furthermore, none of the bidders would guarantee a daily production rate for comparison.

In conclusion, a comprehensive and reliable lease/buy economic analysis requires significant effort and would be meaningful only if performed for a specific need and locale. Also, considerable effort would be required to verify that the contractor laboratories actually meet appropriate level requirements.

CONCLUSIONS

The methods for field analysis developed by the FITs have proven very useful in meeting the specialized goals of site investigation. Advantages of on-site analysis are: data interpretation can direct on-going work through rapid turnaround of results, critical samples can be prioritized and analyzed and analyses can be optimized for a specific site. This procedure can result in better site characterization and more meaningful samples sent to the CLP labs for confirmation and litigation purposes.

Table 4 summarizes the three levels of mobile laboratory capability presented in this review. The "maximum samples/year" is based on the analysis rate times the total number of analysis days/year. To meet this goal, the laboratory must remain on the same site for the entire year (no travel time). The "maximum site/year" is based on only one analysis-day per site. Both of these figures represent obvious extremes that are not practical. They are presented to demonstrate the comparable capabilities of the three laboratories.

Any level of field screening or analysis capability must be justified by the data quality objectives of the field investigation. Therefore, the emphasis of this review is not to recommend a particular laboratory scenario, but to help guide decision-makers interested in pursuing field screening and analysis.

REFERENCES

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Exploratory Drilling into a Buried Uncontrolled Drum Disposal Pit

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ABSTRACT

Several years ago, a remedial investigation/feasibility study (RI/FS) was performed at the Lackawanna Refuse Superfund Site in Old Forge, Pennsylvania. The RI/FS resulted in a recommendation to excavate and dispose of an estimated 15,000 buried drums and the highly contaminated municipal refuse from an uncontrolled landfill area on the site known as Pit 5. Drilling, sampling and monitor well installation were not performed in Pit 5 during the remedial investigation due to concerns for the safety of both workers and the public that always arise at the suggestion of drilling into uncontrolled areas containing buried drums of toxic materials.

Remedial design for this project was begun during the summer of 1985. A Value Engineering (VE) study of the project was performed early in the design phase to assess the cost-effectiveness of various design approaches. The VE study identified the lack of recent information on the following items as a source of project uncertainty that could result in inaccurate estimates of the cost for removal/remediation:

- Depth of Pit 5
- Extent of contamination within Pit 5
- Depth to groundwater/leachate within the pit
- Groundwater/leachate quality within the pit
- Pit stratigraphy

Those in control decided to perform a subsurface investigation of the pit to obtain information needed for safe and costeffective design of the remedial/removal program and to enable a more accurate determination of the cost of remediation. Because of the legitimate concerns for public safety, a specialized drilling technique was designed using technology transferred from the oil and gas industry originally developed for well installation through formations containing naturally occurring pressurized toxic gases. A site-specific program for personnel protection was developed and implemented.

The program was designed in January 1986. The exploratory program was successfully executed in a period between Feb. 10 and Mar. 21, 1986, without significant incident.

This paper will present the design of the drilling and personnel protection programs, their implementation and the results obtained. Also presented will be recommendations for future projects which must consider the exploration and sampling of belowground uncontrolled highly hazardous environments.

BACKGROUND

Remedial Investigations (RIs) may be performed at "buried drum sites" without performing drilling and subsurface sampling into drum disposal pits. Present off-site impacts may be assessed without drilling into drum disposal pits, particularly if the disposal area already is considered to be highly contaminated.

The work plan for performing the RI may emphasize determining the extent of the contamination migration with respect to potential off-site receptors rather than detailed characterization of the source(s). In addition, legitimate concerns for occupational and public health and safety may make investigators hesitant to directly drill and sample buried drum disposal areas.

The need to understand depth, groundwater conditions and chemical characteristics of a buried drum disposal area may, in fact, be critical to properly performing feasibility studies as well as evaluating removal costs, techniques and hazards posed by the removal activity. It may be argued that prescribing excavation and removal of a buried drum area without direct knowledge of required excavation depth, groundwater conditions, chemical characteristics and stratigraphy in the immediate zone of drum disposal entails certain risks during remediation that may outweigh the risks entailed in exploratory sampling of the drum disposal zone.

The Lackawanna Refuse Superfund site contains a buried drum disposal pit which, prior to this study, had not been subjected to exploratory drilling.

CIRCUMSTANCES AT THE LACKAWANNA REFUSE SUPERFUND SITE

Paul C. Rizzo Associates, Inc. (Rizzo Associates) is under contract to the U.S. Army Corps of Engineers, Omaha District, (USACOE) to do remedial design work for the cleanup of the Lackawanna Refuse Superfund site in Old Forge, Pennsylvania. The remedial measures to be designed were prescribed in the site Record of Decision (ROD) issued by the U.S. EPA Region III administrator.

Problem Areas

The Record of Decision was based upon a remedial investigation/feasibility study performed in 1983 and 1984 by a U.S. EPA Zone Contractor. The remedial investigation identified five specific problem areas to be remediated at the site. These areas are:

• Pit 5

Pit 5 contains an estimated 15,000 buried drums of undefined and potentially hazardous materials. This pit was the subject of an NEIC investigation in 1980 during which several test pits were dug and several hundred drums were recovered and assessed. A substantial portion of the contents of these drums was found to consist of organic solvents. The pit also contains municipal and commercial refuse. • Pits 2 and 3

Pits 2 and 3 contain primarily municipal and commercial refuse.

•Borehole Pit

The Borehole Pit apparently was used for the disposal of bulk liquid wastes. Only traces of organic compounds have been detected. Contamination, if any, is believed to lie in the top foot of soil.

• Access Road

Liquids containing heavy metals apparently leaked onto this road; few organics have been detected. Contamination, if any, reportedly is confined to the upper foot of soil.

• Paint Spill

A small area of what appears to be spilled paint was found on the site. High levels of lead have been detected in this material. The material has penetrated the soil less than 1 ft.

Selected Remedial Alternatives

The selected remedial alternatives for each problem area are:

• Pit 5

Excavation, disposal of all drums and highly contaminated wastes off-site, leachate collection and treatment on-site, capping and gas venting

• Pits 2 and 3

Capping, leachate collection and treatment on site and gas venting

- Borehole Pit
 Evenuation of
- Excavation and disposal off-site • Access Road
- Excavation and disposal off-site
- Paint Spill Excavation and disposal off-site

Remedial Design Program

Rizzo Associates initiated design of the remedial action program in July of 1985. The conceptual phase of the design work included assessments of additional informational needs to properly complete the design process. Informational needs that were identified included:

- Depth of Pit 5
- Extent of contamination within Pit 5
- Groundwater level(s) within Pit 5
- Chemical composition of groundwater within Pit 5
- Geotechnical conditions in certain areas of proposed Access Road relocation
- Subsurface conditions at the site of a proposed leachate collection trench at the north end of Pit 5
- Location of a buried sluice pipe beneath the west end of the site access road near the entrance of Pits 2 and 3

Planned Site Assessment

In order to enable completion of remedial design, the USACOE issued a proposed scope of services to Rizzo Associates for supplementary site investigations on Dec. 24, 1985. The work performed included:

- Preparation of an investigation-specific Health and Safety Plan
- Preparation of an investigation-specific Quality Management Plan
- Performance of a site reconnaissance and geophysical survey
- Drilling and sampling of Pit 5 (municipal refuse, mine spoil and groundwater)
- Chemical analysis of samples from Pit 5
- Drilling and sampling of geotechnical borings along the proposed Access Road relocation
- Excavation of test pits at two proposed leachate collection loca-

tions to enable design of the leachate collection system

• Performance of a survey to establish locations of borings and test pits

The balance of this paper describes the activities related to the exploration of Pit 5.

HEALTH AND SAFETY AND QUALITY MANAGEMENT

The Health and Safety Plan for this investigation was initially prepared prior to drilling and finalized to incorporate USACOE comments in March of 1986.

A short summary of this plan is as follows:

- An industrial hygienist served as the on-site investigation supervisor and had complete authority over all field activities.
- All site workers participated in medical surveillance programs and completed site-specific training prior to site activities. Training culminated with written site-specific examination on the health and safety program.
- Extensive personnel protective equipment was required for this project because of the potential hazards associated with site activities. The equipment included outer acid suits, inner Saran Tyvek coveralls, three layers of gloves, boots, boot covers and airline respirators with 5 min. escape capabilities.
- Real-time air monitoring played an integral part of the Health and Safety Plan. Monitoring was performed with a HNU, combustible gas meter, hydrogen sulfide meter and hydrogen cyanide meter. In addition, quantitive personnel monitoring was performed.

The Quality Management Plan (QMP) for this investigation was initially prepared prior to drilling and finalized in March of 1986 to include comments from the USACOE. The QMP included sampling and chain of custody procedures, analytical methodology and statistical evaluation of Quality Control Data. Quality Control Data included calibration, matrix, spikes, duplicates, surrogate standards and independent Quality Control samples.

FIELD INVESTIGATION

Geophysical screening was performed at Pit 5 using a Scintex MP-2000 Fluxgate Magnetometer. The magnetometer was used to indicate relative presence of buried metal (including drums). The boring locations for Pit 5 were selected based upon representative distribution within the reportedly deepest portions of the pit and in areas having lower magnetometer readings than surrounding areas. The purpose of the screening was to minimize the potential for drilling directly into a drum or drum pocket, particularly at a shallow depth.

Drilling at Pit 5 was supervised by Rizzo Associates' personnel, and the drilling subcontractor was John Mathes Associates. Drilling was accomplished using a CHE550 hydraulic rotary, four-wheel drive drill rig with a continuous cavity pump. Potable water was used as the drilling fluid.

At each boring location, a primary and secondary surface collar were installed. The surface collar consisted of a 5-ft section of 4-in. steel pipe used to prevent surface runoff from entering the borehole and, as explained later, to aid in the control of gaseous releases from the borehole. All surface collars were installed with PVC caps on the bottom to seal off the bottom boring until drilling commenced.

The surface collar holes were drilled with an 11-in. flight auger to a depth of 4.5 ft. Plastic sheeting was placed around the boreholes prior to augering to collect cuttings. Concrete was used to set the collar and to seal off exposed refuse areas below ground surface. Continuous air monitoring was performed during augering, as well as during drilling and monitor well installation.

The surface collars were allowed to set up at least 24 hr before drilling occurred. Then a device to control liquid and gaseous releases from the borehole was screwed onto the threaded surface collar, thus making a closed system.

KELLY ROD KELLY SWIVEL KELLY HOSE ALL-VALVE OPERATED POTABLE THREADED STEEL ADAPTER CASING RUBBER GASKET NCLOSED RETURN CROLIND SURFACE KIKIKÌŘ UKUKUKUKUKUKUKUKUK 4" FLEXIBLE PIPE THREADED BALL-VALVE (EMERGENCY SHUT-IN) CONCRETE THREADED 4"1.D. STEEL SURFACE CASING NW CASING (N.T.S.)

Figure 1 Schematic Diagram of Gas Control System Utilized at Pit 5 (Lackawanna Refuse Site)

The gas control system designed for this project included a threaded ball-valve which attached to the 4-in. I.D. surface collar; this valve served as the emergency shut-in mechanism in the event of gaseous release from the borehole (Fig. 1). A steel adapter is screwed into place above the ball-valve and acts to divert any return flow of drilling fluids and cuttings through a section of 4-in. flexible corrugated pipe and into an enclosed return tank. The adapter also has an attached rubber gasket at the top. The purpose of the rubber gasket is to seal off the annular space between the casing and the adapter, while allowing the casing to advance through the gas control system.

Drilling was accomplished utilizing a wireline operated tri-cone roller bit with a diamond tipped casing advancer (Fig. 2). The casing was advanced through the stationary gas control system and surface collar. During drilling, the walls of the boring were sealed off by the casing and the only downhole open area was at the bottom of the boring. Water was pumped down the inside of the casing and out of the drill bit, returning up the annulus of the borehole or, more typically, lost to the formation.

The purpose of drilling with water was to aid in removal of drill cuttings from the bottom of the borehole, to mitigate escape of vapors from the borehole and to lubricate the drilling. Drilling water and cuttings generally were lost to the formation. (Return for all six borings totaled less than 15 gal). Air monitoring during drilling indicated that the system was extremely effective in preventing gas releases. Once the casing penetrated the bottom of the disposal pit, drilling and sampling operations were continued with negligible releases to the breathing zone.

Soil samples were collected with a 24-in. standard penetration test (SPT) split-barrel sampler on 5-ft centers. After drilling to the required sampling depth, the casing was unscrewed at the surface, above the gas control system. Care was taken to assure the boring was completely full of water. An overshot latching device was lowered down the inside of the casing by a hoist-operated wireline cable. The roller bit and sub were picked up by the overshot latching device and brought to the surface. The SPT sampler then was lowered inside the casing attached to AW rods and the sampler was driven using a cat-head operated 140 lb weight.

WRELINE CABLE



Figure 2 Schematic Drawing of Wireline Drill Bit and Reaming Shoe Utilized at Pit 5 (Lackawanna Refuse Site)

After the SPT sampler was removed from the borehole, the roller bit and locking inner sub were lowered to the bottom of the boring by wireline, where they locked into the casing advancer and drilling continued. Samples were screened using real-time instrumentation for radioactivity, hydrogen sulfide, hydrogen cyanide, organic vapors (PID) and an explosimeter.

This drilling and sampling method provided a means of obtaining representative soil samples with no collapse of the borehole walls while preparing to sample. This method also proved effective in mitigating gaseous vapor releases from the borehole. The casing effectively sealed the borehole walls while the water in the borehole contained the bottom of the boring. Any vapors escaping up the annulus were trapped in the return tank where they could be contained and monitored.

A monitoring well was set at each boring location following soil sampling. The wells consisted of 2-in. galvanized steel riser pipe and 2-in. stainless steel well screen (0.01-in.) with PVC caps. After the final soil sample was retrieved, the well screen and riser pipe were lowered into the hole by wireline, with the casing in place and the borehole full of water. The casing was removed in sections, and the refuse material was allowed to collapse against the well.

Pulling casing above the base of the disposal pit generally was the phase of operations most susceptible to release of gaseous vapors from the borehole. Measureable amounts of both methane and hydrogen sulfide were detected for a period of a few minutes at one boring during this phase of monitor well installation. These releases were controlled by filling the borehole with water. Twenty feet downwind of the boring location, there were no instances of detection of gaseous releases and, therefore, no measureable off-site releases.

The need to use the emergency shut-in ball valve never arose, as all gas releases were controlled by filling the borehole with water. In the event of an uncontrollable gaseous release, the casing would have been pulled off bottom, unscrewed at the surface and dropped below the surface and the ball-valve closed.

The major drawback to the gas control system utilized at this site is that unconsolidated garbage and/or soil may collapse around the bottom of the casing, possibly prohibiting the casing from being lowered below the ball-valve assembly. This problem could be remedied by having the ball-valve installed in a short (1-ft) piece of casing immediately below the kelly swivel. This adaptation would remove the need to lower the casing below the ball-valve, and the well could be shut-in at any time during the operation.

The installation of the surface collars proved to be an important part of the drilling process. Surface collars must be vertical in order to allow the boring to be drilled without major deviation. In one boring location, the surface collar set up slightly out of level. After the boring depth reached approximately 30 ft, the boring had to be terminated due to hole deviation.

The use of the tri-cone roller bit and casing advancer with

	DEPTH, FT.	SAMPLE	SAMPLE RECOVERY (IN.)	BLOWS PER 6 IN. INCREMENT	PROJECT NAME: <u>LACKAWANNA</u> <u>COORDINATES</u> N <u>446,220,941</u> E <u>2,546,790,301</u> SURFACE EL: <u>955,7'</u>	HAU VOLATILE READING (PPM)	REMARKS BEGAN DRILLING 3-6-86/0840 HRS.
	- - - - - -	AUGEI S-1	-		AUGER CUTTINGS SHOWED BROWN, FINE-MEDRUM SAND AND SILTY CLAY, WITH ASSORTED TRASH AND TIRES (WET AT 3.5').	25	J-4-86 SET 1-4' STEEL SURFACE COLLAR WITH 11" STEEL AUGER TO 4.5'. (SAMPLED AT AUGER TIP) NOTE: HOLE FILLED WITH WATER TO 3.5' WHILE SETTING COLLAR-NO WATER ADDED TO CONCRETE MIX
	- 	X	5	20-24 25-15	BROWN, FINE SAND AND SILT (MOIST), GRAY BROWN SANDSTONE FRAGNENTS, BLACK CARBONACOUS SHALE AND COAL FRAGMENTS, WOOD AND PAPER. ~BASE OF GARBAGE PIT ~14.5	40	NOTE: NO RETURN CIRCULATION DUE TO WATER LOSS IN GARBACE S-2 LAB SAMPLE (9.5'-11.5') OROVE SPOON 3 TIMES.
Ē	- 15	\$	16	8-15 24-25	BROWN, FINE SAND (MOIST) DENSE, TRACE TAN SILT, DARK GRAY SHALE, COAL FRAGMENTS, OCCASIONAL SANDSTONE FRAGMENTS (SPOIL).	8	S-3 LAB SAMPLE (14.5'-18.5') OROVE SPOON 1 TIME. HARD DRILLING 14.5'-18.8' EASY DRILLING (VOID) FROM 18.8'-19.5'.
	20	X	12	6-8 9-11	Brown, Fine Sand and Silt (Moist) Medium dense, brown hard Sandstone Fragments throughout, carbonaceous shale and coal fragments common (spor).	2	S-4 LAB SAMPLE (19.5'-21.5') DROVE SPOON 2 TIMES.
	25	X	18	4-7 7-10	BROWN, FINE SAND (MOIST) MEDIUM DENSE, WITH SANDSTONE FRAGMENTS INTERMIXED, TRACE , SHALE FRAGMENTS (SPOL).	0.5	S-5 LAB SAMPLE (24.5'-28.5') DROVE SPOON 1 TIME.
5	<u>ж</u> _Г						NOTES:
DA DA FIE CH	PROJECT NO.: <u>85-208</u> DATE BEGAN: <u>3-8-88</u> DATE COMPLETED: <u>3-7-86</u> PELD ENG./GEOL.: <u>WAB/KJB</u> CHECKED BY: <u>PF0</u>			205 5-85 3-7-86 WAB/KJ PFQ	UNC: UPC: UPC: <td< td=""><td>1.51 2. 0 0 0</td><td>140 ID. HAMMER USED TO DRIVE T SAMPLER. OPERATIONS MONITORED TH HINU OWA, RADIATION MONITOR, OCOSWETER, HON METER, AND S METER. ONLY VALUES S SIGNIFICANCE ARE SHOWN.</td></td<>	1.51 2. 0 0 0	140 ID. HAMMER USED TO DRIVE T SAMPLER. OPERATIONS MONITORED TH HINU OWA, RADIATION MONITOR, OCOSWETER, HON METER, AND S METER. ONLY VALUES S SIGNIFICANCE ARE SHOWN.

Figure 3 Log of Boring No. P5—4

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r -				SANDSTONE FRAGMENTS, MEDIUM DENSE (SPOR).	ł			
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Figure 3 (Continued) Log of Boring No. P5---4

ретн, гт.	SAMPLE	SAMPLE RECOVERY (IN.)	BLOWS PER 6 IN. INCREMENT	PROJECT NAME: <u>LACKAWANNA</u> <u>COORDINATES</u> N <u>446,220,841</u> <u>E 2.546,790,301</u> SURFACE EL: 955,7	HNU VOLATILE READING (PPM)	REMARKS			
	×	5	10-14 18-12	BROWN FINE SAND AND SILT, WITH BROWN WEATHERED SANDSTONE FRAGMENTS, MEDIUM DENSE (SPOIL). DARK BROWN FINE SILTY SAND. DARK GRAY- BLCK, CARBONACEOUS SHALE, TRACE DARK	0	VERY HARD DRILLING 63.0'-64.5'			
	XI	12	13-14 5021	BROWN WEATHERED SANDSTONE. VERY DENSE (SPOIL).	٥				
				BOTTOM OF BORING AT 56.5" NOTE: INSTALLED 2" MONITOR WELL 3-7-86 0"-20" 2" GALVANIZED RISER PIPE 20"-30" 2" STANLESS STEEL SCREEN (0.01") 30"-34" BENTONTE 34"-56" GALVANEL SCREEN (0.01") 34"-56" COLLAPSED BORING MATERIAL					
PROJECT	NO.:_	<u>65-</u>	208	GWL: DEPTH 19.15' DATE/TIME 3-14-85/075	5.	NOTES: 140 Ib. HAMMER USED TO DRIVE			
DATE OUNDIETED 3-7-84					9 S	SPT SAMPLER. 2. OPERATIONS MONITORED WITH HNU OVM, RADIATION MONITOR, EXPLOSIMETER, HON METER, ANO			
FIELD ENG./GEOL : WAB/KJB				TRI-CONE ROLLER BIT, WITH NW DIAMOND	Ĕ				
CHECKED	BY: _		PFQ	TIPPED CASING ADVANCER.	H2S METER. ONLY VALUES				

Figure 3 (Continued) Log of Boring No. P5—4 water as a drilling fluid along with the gas control system proved to be both a safe and effective means of obtaining soil and groundwater data from landfills containing buried drums of unidentified and potentially hazardous materials.

The drilling, sampling and well installation program took 17 work days and was performed in February and March of 1986. Air temperatures ranged from 10°F to 40°F, with typical lows in the mid-teens and typical highs in the low 20s. There was one day lost to bad weather (steady rain at 40 °F). Weather conditions proved close to ideal for working in the personal protective gear required for the project.

Fig. 3 is a typical log from an exploratory boring. Fig. 4 is a typical monitoring well installation diagram.



WELL COORDINATES ARE: N448,344.193 E2,546,785,208



The detailed discussion of the chemical analysis protocols is beyond the scope of this paper.

RESULTS

Refuse, spoil and groundwater samples were analyzed in this investigation for HSL compounds, cyanide and organic non-HSL compounds.

The most frequently detected analytes in refused samples were common organic solvents including acetone, ethylbenzene, toluene, xylenes and several other ketones. These compounds are the most predominant compounds detected in all matrices. The concentration of the individual volatile compounds ranged from non-detectable to 67 ppm, although the concentrations are not statistically different from concentrations found in typical refuse (Pits 2 and 3). Semi-Volatile Organic Compounds (SVOC) detected included polycyclic aromatic hydrocarbons and phthalates. The SVOC concentration were from non-detectable to 59 ppm. Chlorinated organic compounds were not measured frequently; when they were detected, the maximum concentration was 2 ppm.

Mine spoil from below the refuse zone was sampled and analyzed. Samples collected in this zone indicate a rapid decrease in number of compounds detected and concentration with depth. Within 5 ft of refuse base, contamination is negligible. Compounds detected in this zone are typified by the volatile organic compounds measured in the refuse.

Water (leachate) samples displayed the highest concentration of volatile organic compounds (VOC). A few SVOC (phthalates and phenolics) were detected at levels below 1 mg/l. Concentrations and compounds vary greatly between closely spaced wells. Concentrations and the variety of compounds detected increased toward the north end of the pit. Water levels ranged from 5 ft below ground surface to over 25 ft below ground surface.

The following information was generated by this investigation and has been used in completing the design process:

- The depth of refuse disposal in Pit 5 was relatively uniform, varying between 15 and 19.5 ft below ground surface. This information was used to estimate excavation volumes which affect cap design, backfill requirements, staging areas, analytical tests, etc. Previous estimates of disposal depths ranged up to 50 ft.
- Water in the pit is probably in perched zones, based on water levels and water quality. The volume of water is important for excavation dewatering, and the quality of the water is needed for disposal cost estimates and treatment system design. There was no previous information on water levels and water quality within Pit 5.
- Chemical analysis verified the ROD determination to use target compounds as indicators of contamination. The target or indicator compounds are selected volatile organic analytes. The indicator concept allows relatively economical and quick determination of the required disposition of Pit 5 material.
- Mine spoil is not highly contaminated, and significant contamination is confined to the refuse zone.
- Analytical results coincide with the findings of the NEIC.
- There is potential methane and H2S release during excavation. ٠
- Overall analytical results are indicative of "typical" refuse. Pit 5 refuse was not found to vary significantly from Pits 2 and 3 refuse in content or concentration.
- A pocket of groundwater within the pit showed the influence of the drummed materials. The water samples from Wells P5-1 and P5-2 contained 2-butanone, 4-methyl 2-penthanone and toluene at levels greater than would be expected in a sanitary landfill. The other three groundwater samples were not felt to be anomalous with respect to what could be expected with a sanitary landfill.

In summary, sufficient information has been obtained to permit a rational design and cost estimate for the excavation and removal program for Pit 5.

CONCLUSIONS

The following conclusions can be made:

- Pit 5 at the Lackawanna Refuse site is shallower and less highly contaminated with respect to background than previously believed.
- Pit 5 contains significant zones of perched water that exhibit large variations in pheratic level and water quality over relatively short distances.
- Some of the groundwater within Pit 5 exhibits significant contamination related to the drum disposal activities.
- It has been confirmed that it is possible to drill, sample and install monitor wells in a drum disposal pit in a manner that does not compromise the health and safety of the work force or the public.

ACKNOWLEDGEMENTS

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Statistical Approach to Groundwater Contamination Mapping with Electromagnetic Induction: Data Acquisition and Analysis

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ABSTRACT

A field-to-finish procedure to quantitatively measure electrically conductive subsurface contamination with surface electromagnetic induction (EMI) is described. The procedure exploits the rapid data acquisition feature of EMI to build a statistical data base for data processing and interpretation, where inverse modeling is the core of the interpretation technique. The statistical approach validates and enables the use of statistical diagnostic tools to test and guide the otherwise intractable inverse modeling process. This paper focuses on the use of those statistical diagnostics in the interpretation process. To evaluate the final results of inverse modeling, a comparison is made with a vertical cross-section obtained from a set of vertical logs taken with a borehole induction logger. This study shows, by way of a case study, some capabilities and limitations of the EMI method and the results of inverse modeling of 116 vertical soundings. The degree of detail to which EMI can describe the subsurface using the statistical approach is shown.

INTRODUCTION

Detecting and monitoring subsurface contamination is accomplished by either direct measurements from monitoring wells or by remote sensing surface geo-electrical probing and soil organic vapor analysis. Geo-electrical probing often uses electromagnetic induction that measures the electrical conductivity of the earth to obtain information about the subsurface. Data acquisition is either profiling (or gridding), in which a series of measurements are made at one instrument configuration at regular sampling intervals along a transect (or along parallel transects in the case of gridding), or vertical sounding, in which a set of measurements utilizing all available instrument configurations is made at selected station locations. Profiling data can be interpreted in rare cases where the subsurface structure is known to be homogeneous and isotropic and where the data are free of cultural noise. In most cases, however, the subsurface structure is neither known nor well behaved so that the vertical sounding technique must be used to model the structure and to extract the contamination value from the model. Techniques for analysis and interpretation of geo-electrical soundings have been developed and generally are successful, but these applications have involved deeper targets (oil and minerals) than in hazardous waste studies. Most targets here are located in the aquifer which can be found from the surface to tens of meters below the surface, whereas in the mining and petroleum studies, the targets can be hundreds to thousands of meters below the surface.

In hazardous waste studies, most reported case studies using geophysical surface measurements have involved only profiling. The interpretation of the resulting measurements is difficult because of noise, a need to know the subsurface structure and a need to understand the instrument response. Electrical soundings have been used for these applications,' but the problem was not treated consistently in a manner that addressed the special problems inherent in hazardous waste studies. This paper presents a method of using Electromagnetic Induction in a field-to-finish procedure that addresses the problems of cultural and geological noise, low instrument resolution and anisotropy and inhomogeneity of the subsurface. The procedure involves a consistent statistical approach that takes advantage of a sophisticated vertical sounding interpretation program (Inverse Modeling) and allows data processing of the raw field data. This procedure provides a system of internal and external checks on the otherwise obscure Inverse Modeling procedure and hence guides the investigator in the analytical process.

OBJECTIVES

The primary objective of this paper is to illustrate the efficacy of a statistical approach to Electromagnetic Induction (EMI) surface geophysical remote sensing in the detection of electrically conductive subsurface contamination. The approach attempts to exploit the advantages of EMI to mitigate the problems of surface geophysical probing and to provide valid and consistent data for interpretive procedures. Furthermore, the use of statistical diagnostic output from Inverse Modeling to guide interpretation of the modeling process is examined. For evaluation, a comparison of the information obtained from the use of computer inverse modeling is made with results obtained from a borehole induction logger.' A further objective was to examine the limitations of the EMI surface probing method in cases involving high subsurface conductivities. The case used to meet the objectives in this study involves an electrically conductive groundwater contamination plume that resulted from chemical wastes being dumped into unlined surface containments.

STATEMENT OF THE PROBLEM

The problem of measuring electrically conductive subsurface contamination by EMI is complicated by a number of factors including: (1) instrument limitations, (2) cultural interference and (3) the inherent non-uniformity of the subsurface geology. Instrument limitations arise because of the nature of the electromagnetic fields and the difficulty of isolating the signal from the primary field which lead to a low signal-to-noise ratio and a relatively low vertical depth resolution. The vertical response of the instruments allows a relatively high resolution for the top 3 m, but an increasingly lower resolution with increasing depth. Although more suitable instrumentation could be designed for shallow applications, the resolution most likely would not be greatly improved. Examples of cultural interference are buildings, fences and buried metal as well as electrical noise caused by radio stations, machinery and power lines. The effects of some of these can be mitigated by an increased signal-to-noise ratio which again required improved instrument design that invariably leads to compromises in other areas. The third factor requires the most ingenuity in interpretation. The earth is inherently complex because of complicated layering structure, inhomogeneity, anisotropy and geological noise, and, to further complicate matters, the geology can vary greatly over a few meters. The varying geology can be referred to as producing a spatial variability having a short range of correlation, a fact that we will use later in our analysis. The complexity means that the subsurface rarely is comprised of several thick, flat, homogeneous and isotropic layers. Furthermore, geological noise (small volumes of earth having significantly different physical and electrical characteristics) can make the problem of understanding the picture most difficult. Sophisticated two and three dimensional modeling techniques have been studied with varying degrees of success, but the complicity of these studies precludes them from most hazardous waste studies because of time, money and expertise requirements.

APPROACH

Our approach is to accept the above limitations and to use available instrumentation and a one-dimensional modeling technique that allows the use of straightforward data acquisition, data processing and data interpretation. Effects of noise and low resolution will be mitigated with improved data acquisition and processing. This translates to obtaining sufficient data to allow digital filtering techniques to reduce noise effects in the measured data and to provide statistical input to the interpretation process. The EMI instruments lend themselves to this approach, because data acquisition is fast and can be taken in physically relatively small areas. To mitigate the two and three dimensional effects that will be lost in the one dimensional analysis, consideration will be given to the spatial correlation of the variables in the interpretation.

The model shown in Fig. 1 is the basis of the interpretation that will be used in this study. In this model, we assume that the sub-



Figure 1 Model Used in Inverse 1

Simplified 3-Layer Model Used in Inverse Modeling. Examples of 10, 20 and 40 m Coil Configurations Are Shown at Station P.

surface is comprised of several layers, all of which are onedimensional; they are flat, and the electrical properties are constant over the entire volume. This is equivalent to saying that each layer is homogeneous throughout its thickness and isotropic horizontally in all directions. A model such as this is a necessary simplification in view of the low resolution of our geophysical technique, and it allows us to apply standard data interpretation techniques to determine the model parameters. Here the parameters are the layer thicknesses and the layer conductivities. The second layer will represent the aquifer and, in general, it will be the conductivity of this layer that is of interest. In our modeling procedure, however, all parameters initially will be calculated.

PROCEDURE

The procedures used in this study will be illustrated by example. A site in Pittman, Nevada (Fig. 2) with a documented groundwater plume was used. The contamination originated from organic and inorganic chemical wastes that were dumped into unlined surface containments beginning in about 1945 and subsequently entered the groundwater. The transect selected for this study crosses the groundwater plume about 2 km from the source. Total dissolved solids concentrations of 20,000 mg/l were measured by direct sampling of water samples from monitoring wells along the transect.



Figure 2

Case Study Site at Henderson, Nevada, Showing the Pittman Transect. Cultural Noise Sources Relating to the Study Are Shown.

Instrumentation

The instruments used in this study were the Geonics EM31 and EM34-3. These units, although not designed for sophisticated sounding applications, are electrically stable, dependable and afford a reasonable range of coil configurations. A coil configuration in this paper will refer to a particular combination of coil separation and coil orientation. The set of configurations here are 3.7, 10, 20 and 40 m coil separations at both the horizontal and vertical dipole mode, for a total of 8 unique configurations. The EM31 has a fixed coil separation (3.7 m) and can be held at several heights above the ground for additional depth information.

Data Acquisition

Data were taken along the 1200 m transect (Fig. 2) in the sounding mode at intervals of 10 m. The sounding mode requires multiple measurements at each station, hence a measurement was made every 10 m with each coil configuration with the EM34-3. These were 10, 20 and 40 m coil separations using both vertical and horizontal dipoles giving a total of 6 measurements. Measurements were made every 5 m with the EM31 at 0 and 1 m heights above the ground with both horizontal and vertical dipoles. The EM31 measurements were taken each 5 m because of the shorter coil separation and the higher spatial variability of the surface layer to which the shorter coil separations are sensitive. A total of 960 EM31 measurements and 720 EM34-3 measurements were made in one man-week of field time.

Fig. 3 shows a sample plot of EM34-3 10-m field data for the first 60 stations. The data density allows an immediate visual analysis for electrical and geological noise. Comparison of the curves for the vertical and horizontal dipoles shows that, for apparent conductivities over about 100 millimho/m, the measured values for vertical dipoles decreases for an increase of actual subsurface conductivity, and the curves of the vertical dipole data show more periodic electrical noise indicating its higher susceptibility to this noise. These effects that result from the instrument design and the nature of the electromagnetic fields are discussed in a previous paper.' Similar visual analysis can be made for the curves for the other instrument configurations. Comparisons between configurations also will give information about the noise.



Figure 3 Example of EM34-3 10-m Field Data from the Pittman Transect. Smooth Curves Are the Data after Digital Filtering.

From these curves, it is clear that noise can cause variations of measured values of apparent conductivity of about 40 to 50% from their mean values, thus making interpretation based on them difficult without further processing and modeling. The next step was to process these data to mitigate the noise. This analysis involved Fourier analysis and digital filtering to eliminate the periodic noise components. The results of this processing are shown in Fig. 3 for the 10-m measurements along with the original data.

Inverse Modeling

The data now are ready for interpretation by Inverse Modeling. Inverse modeling is a computerized program that fits a model (in this case, the one-dimensional model in Fig. 1) to the measured data.⁴ The basic operation of the inverse model is shown in Fig. 4. For each station (i.e., for each vertical sounding) the mean value and its standard deviation (explained below) for each of the 10 measurements are input into the program. The number of layers (3 for the EMI), and an estimate of their thicknesses and conductivities are input as the starting values for the model. The inverse model uses these starting values to calculate the apparent conductivities that would be measured at the 10 coil configurations used



Figure 4 Block Diagram of the Computer Inverse Model Used in this Study

in the sounding. These calculated values $\sigma_{a_i}^{calc}$ then are compared with the actual measured values $\sigma_{a_i}^{meas}$ in the least square sense; the squared error

S.E. =
$$\sum_{i=1}^{N} [\sigma_{\epsilon_{i}}^{meas} - \sigma_{\epsilon_{i}}^{calc}]^{2} / S_{i}$$
 (1)

is calculated where i is summed over the 10 coil configurations. The task of the inverse model is to make changes to the original model parameters, i.e., the layer thicknesses and conductivities, in such a way that the S.E. decreases. It continues this process iteratively until the change in S.E. is below a user specified value, then proceeds to the next station after the final model parameters and the statistical information are written to a file.

At this point it should be mentioned that a previous study attempted to simplify the inverse modeling technique³ by using a linearized procedure suggested by the instrument manufacture. This procedure did not produce satisfactory results because of conductivities that exceeded the low induction number approximation,⁴ therefore, an inverse model that does not depend on this approximation must be used. Unfortunately, most cases of interest seem to exceed the approximation.

Input to Inverse Model

The filtered data are input into the program in the form of means and standard deviations of the apparent conductivities. The means in this case are the averages over 40 m, 20 m each side of the station, because isotropy is assumed over this range, and the longest coil separation integrates over 40 m. The standard deviation can be considered to consist of two components, one from electrical and geological noise and one from the actual change in the subsurface structure (anisotropy) over the length of the model. The noise component $S_{k_1}^{i}$ is calculated by taking the varance of the difference between the filtered data and the original data over the 40-m range, i.e.,

$$S_{kj}^{1} = \sqrt{\sum_{i=j-L}^{j+L} \frac{(q_{ki}^{raw} - \sigma_{jki}^{filt})^{2}}{2L+1}}$$
(2)

where L is the number of stations on each side of the station, j, that are included in the calculation, and k is the coil configuration. The anisotropy component S_{kj}^2 , also calculated over the 40-m range, is defined as

$$S_{kj}^{2} = \sqrt{\sum_{\substack{j=j-L}}^{j+L} (\sigma_{jki}^{\text{filt}} - \sigma_{kj}^{\text{mean}})^{2}}$$
(3)

where S_{kj}^{mean} is the mean value of apparent conductivity for the jth station.

The sum of the two components S_{kj}^{lotal} is the standard deviation that is necessary in the Inverse Model program to make the rows of the matrices have equal variance.

After the means and standard deviations were calculated for the Pittman Transect using the above procedure, and a 3-layer model was estimated based on well data, inverse modeling was done at 116 consecutive stations along the transect.

Although the objective of this groundwater contamination study is to define the subsurface contamination, it is necessary to calculate all layer parameters unless some are known. In the latter case, they can be constrained to the known values. Since we want to demonstrate the efficacy of the EMI for determining the subsurface model, we originally have required the program to calculate all layer parameters.

Statistical Diagnostic Tools

Before the modeling results are analyzed, it is necessary to briefly describe the principal statistical diagnostic tools. These "internal" diagnostics provide a check on the procedure; they tell how well the procedure is working. They do not necessarily tell if the results correspond with the real world.

Squared Error

The squared error, defined above, is a measure of how well the program was able to fit the model to the data. Usually, this error can be made small by increasing the number of adjustments to the parameter, i.e., the number of iterations that the program makes. If it is not able to fit the data, it could mean excessive noise in the data, an entry error or an inadequate number of layers in the model. On the other hand, a good fit does not necessarily mean that the model obtained is a true representation of the real world. It is one piece of information that will aid the interpretation.

Percent Residual

The percent difference between measured and calculated values of apparent conductivity for the ith coil configuration is

$$\mathbf{R}_{i} = [\sigma_{\mathbf{a}_{i}}^{\text{meas}} - \sigma_{\mathbf{a}_{i}}^{\text{calc}}] \times 100 / \sigma_{\mathbf{a}_{i}}^{\text{calc}}$$
(4)

 R_i gives specific information on the fit of the ith coil configuration and can be used to determine if an instrument calibration problem exists. For example, if the 40-m vertical dipole residuals were consistently low or high, one might suspect that the instrument calibration is incorrect; if the residuals for the longer coil separations were large, one might suspect that the model is not being fit well at greater depths. Again, it is another piece of the puzzle.

Parameter Standard Deviation

This quantity is a statistical parameter that is generated from the least squares regression algorithm that fits the model to the data. A mathematical expression for it is not helpful here since it involves matrix algebra and a discussion of biased estimators. The PSD is an internal diagnostic that gives the investigator a flag if the program is not able to fit the parameter well. A high value of PSD indicates that the parameter cannot be trusted because of highly correlated measurements or parameters, layers that are too thin or deep, etc. For example, if the model estimates a parameter to have a value of 50 and a PSD of 3, the standard interpretation would be that the true value lies between 44 and 56 with a 96% certainty. The preferred interpretation here is to look at the relative values of PSD and simply use high values as a flag that a problem might exist for that parameter.

Parameter Correlation Matrix

The elements of this matrix show the correlation between any two parameters. A high correlation (near plus or minus 1.0) between two parameters means that the probability is low that each can be individually determined. The product or ratio sometimes can be determined in these cases. A value near zero means that the parameters are not correlated. A typical case is that for a deep layer, only the product of thickness and conductivity can be well defined since the surface measurements could be caused by a thick layer of low conductivity or a thin layer of high conductivity. This matrix usually is not used directly in the interpretation, but rather as a check to see why some parameters are not well defined.

Reference for Validation:

Before we return to the case study, it is important to establish a method of comparison with the real world. This is an "external" check that is desired to evaluate the results of inverse modeling. At this site, a comparison was made with a vertical cross-section (Fig. 8) obtained from interpretation of borehole induction logs taken by the manufacturer² with a Geonics EM39 unit. The EM39 measures the electrical conductivity in the borehole using the same principle of electromagnetic induction that is used by the surface instruments. The vertical resolution of this instrument is high and does not depend on depth as in the case of the surface units. The volume of earth measured by this logger is small, meaning that local lateral variations (geological noise, inhomogeneities, etc.) can strongly affect the measurements. The interpretation in Fig. 8 was based on 15 vertical logs made at 200-ft intervals from station 36 to station 117 using a forward model program supplied by the manufacturer. It should be understood that, although the vertical resolution of the downhole probe is high, the interpretation between stations is made assuming a spatial continuity that is not shown by this technique.

INTERPRETATION

We now return to the case study to demonstrate the use of these diagnostics. Because of space limitations, only a few steps of the analysis will be given to illustrate the procedures.



Figure 5 Output from the First Runs of Inverse Modeling for the first 60 Stations. Shown are: (a) Vadose Zone Conductivity, (b) Aquiclude Conductivity, and (c) Water Table Elevation.

Fig. 5 shows the results of the initial runs for the vadose zone and aquiclude conductivities and for the vadose zone thickness for the first 60 stations. These examples were chosen to show some of the features of the EMI and the data acquisition method. Fig. 5a shows the vadose zone conductivity profile as a fairly smooth varying function of distance along the transect. Furthermore, a comparison of this representation with Fig. 8 shows that the relative values compare well, that is, both representations show maxima in the region of station 40 to 50. A discrepancy in absolute value is not surprising since the borehole measurements are localized values, whereas the surface instruments average over larger volumes of earth. In Fig. 5c, the results for the vadose zone thickness also compare favorably with the measured values (from monitoring wells) shown in Fig. 8 except in the region 40-50. This problem can be understood by noting that the top layer conductivity is extremely high in that region. This has the effect of sharply limiting the depth of penetration of the EMI instruments,' and hence their sensitivity to resolving layers at depth. This effect also can be seen in Fig. 3 as a strong anomaly in the 10-m vertical and horizontal dipole raw data and is evidenced by an anomaly in the aquiclude conductivity in Fig. 5b. The extremely high nearsurface conductivity, therefore, masks the deeper phenomena and sets a limit for the EMI instruments. This is the limitation this study targeted to examine.

We now turn to an analysis that exploits the statistical nature of our procedure. The first step involves a visual inspection of the parameter curves for values that depart radically from their neighbors. Anomalous values are suspect because the station interval (10 m) is small compared to the length of the maximum coil separations (20 and 40 m) and compared to the range of spatial correlation displayed by the field data. Considering this, we suspect that no great change in layer parameters should take place over 10 or 20 m, rather, that the change will be a smooth transition to higher or lower values. This statement is a consequence of results borrowed from Geostatistical analysis of the data that state that the values of a spatially correlated random variable will vary smoothly within the range of correlation.'

Station 6 (Fig. 5), for example, shows a strong anomalous value for the aquiclude conductivity (10 millimho/m). Referring to Table 1, one sees that its Parameter Standard Deviation is very large (4.10) compared to neighboring values (about 0.03). This indicates that the program considers the reliability of that value to be low. The problem in this case (and for station 36) was caused by data entry error. A different type of problem was encountered for stations 15-20 that exhibit an almost zero (< 1 millimho/m) top layer conductivity. The parameter standard deviations in this case were very large (Table 1), again telling us that the program had a difficult time assigning values to that parameter. Here, however, the problem was in the limitations of the computer; the conductivity values became so small that the mathematical algorithm was becoming unstable. The solution was to assign a larger minimum value (1.0 millimho/m) to the top layer conductivity. This prevents a smaller value from being assigned. A further analysis of the region between station 40 and 50 reveals high values of parameter standard deviations (Table 1) for the aquiclude conductivity and for the top layer thickness, but they were not consistently high. As discussed previously, this is a case where the limitation was caused by the geophysics and was not consistently reflected in the modeling diagnostics. If the cause of an anomaly

 Table 1

 Example of Parameter Standard Deviations

Station	Aquiclude	Station	Vadose	Station	Aquiclude
1	0.03	11	0.85	41	10.73
2	0.06	12	1.03	42	0.23
3	0.16	13	0.30	43	0.28
4	0.04	14	1.10	44	3.91
5	0.04	15	78.79	45	10.59
6	4.10	16	26.77	46	164.53
7	0.10	17	95.68	47	7.64
8	0.30	18	45.20	48	1.00
9	0.18	19	126.63	49	5.80
10	0.13	20	0.73	50	83.98

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is not certain, the other statistical tools could be used to help resolve the ambiguity. For example, the percent residuals could be compared to see which coil configurations are being best fit, and the squared errors could be compared. Furthermore, the correlation coefficient matrix would tell if the parameters were too strongly correlated to be resolved.

At this point, a better understanding of the initial modeling has been gained. To improve the model further, it is necessary to exploit that understanding. Knowing that the resolution of the top layer parameters is the greatest and making an assumption (based also on well logs) that the clay aquiclude conductivity is continuous (spatially correlated), the top layer thickness and conductivity and the aquiclude conductivity were constrained to values obtained by smoothing the curves obtained from modeling. The inverse model then was required only to adjust the aquifer thickness and conductivity.

Figs. 6 and 7 show the final results. Fig. 6 shows the detailed aquifer conductivity profile, whereas Fig. 7 is a composite of all of the parameters where the parameter profiles have been averaged over ranges to simplify the representation. A quick comparison with Fig. 8 shows that the EMI has not defined the laver boundaries accurately. Part of the discrepancy can be understood by remembering that the EMI uses electrical rather than physical properties to identify the layers. The layer boundaries therefore are identified by changes in conductivity, not necessarily by changes in geological structure. Next, the model obtained from the borehole induction logs shows a much more complicated layer structure than can be described by 3 layers. The inverse model must find a model that best fits the data with too few layers. This model effectively combines layers giving some kind of an average layer conductivity and places the layer interface where it finds the largest conductivity contrast. The first layer thickness loosely defines the water table, but one must remember that the capillary fringe will move the electrical boundary upwards. This effect is seen when one compares Figs. 7 and 8. A general comparison of the vertical cross-sections in Figs. 7 and 8 reveals that the major contamination features are in fact shown by the EMI crosssection. Again, the averaging effect of the EMI does not allow definition of the detail, but the significant features shown in the borehole cross-section have not been lost.



Figure 6 Final Curve of Aquifer Conductivity Predicted from Inverse Modeling
An interesting outcome of the study, most easily seen from Fig. 8. is that the highest contamination values appear at the bottom of the aquifer or in the clay aquiclude. Conductivity greater than about 200 millimho/m is not typical of the clay itself.² A possible explanation is that, since the clay conductivity is considerably greater than the contaminated aquifer conductivity, the clay has absorbed and retained contamination over time. An even more significant observation related to that result is that this effect is not evident from the raw data or from water sample analysis (not shown). The plume according to the water samples peaks at about station 50, and the raw data (Fig. 6) show the highest apparent conductivities between stations 40 and 50. We know from modeling, however, that the latter values result from a very high surface layer conductivity. This example leads to the conclusion that inverse modeling can give significant information that is difficult or impossible to interpret from profiling data or from water samples.



Figure 7 Geo-electrical Cross-section of the Pittman Transect from Inverse Modeling of Surface EMI Soundings. Conductivity Values Were Averaged over 10 Stations for Presentation.



Figure 8 Geo-electrical Cross-section of the Pittman Transect from Borehole Conductivity Logs. Water Table and Aquiclude Depths Are from Direct (Physical) Measurement.

This brief analysis has shown that this method provides abundant information to guide the analysis and to differentiate between instrument and modeling limitations. Continuing the analysis and interpretation in this manner will allow the investigator to derive the maximum information from the geophysical technique, and by combining this information with that derived from other studies (geology, chemistry, hydrology, etc.), the picture can be improved further.

CONCLUSIONS

Several conclusions can be drawn from this study. First, the EMI instrumentation has a limitation regarding the maximum subsurface conductivity, i.e., high top layer conductivities effectively act as a shunt to the induction of energy into the lower layers. The limitation here occurred at a top layer conductivity of about 400 millimho/m. As predicted by the manufacturer, data from the vertical dipoles configurations for the EM34-3 are not interpretable for layer conductivities over about 95 millimho/m without correlating them with data from the horizontal dipole configurations. This limitation, however, was compensated for in the analysis by using the high data density combined with the spatial correlation of the data. Next, the vertical dipole configurations are much more sensitive to electrical noise than the horizontal dipole configurations. These are convincing arguments for the necessity of vertical soundings and subsequent inverse modeling of the data.

Finally, a product of a consistent field-to-finish statistical approach is a set of diagnostic tools that enables the investigator to analyze the interpretation at each step of the process. The EMI technique used here, despite the limitations of the instruments, was able to show the important features of subsurface contamination with this interpretation procedure.

DISCLAIMER

Although the information in this document has been funded wholly by the U.S. EPA under cooperative agreement CR 812 189 to the Environmental Research Center, this paper does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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Processes Affecting the Interpretation of Trichloroethylene Data From Soil Gas Analysis

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ABSTRACT

The use of soil gas analysis data in remedial investigations has increased in recent years. These data have been used to design monitoring systems, to identify areas having soil and/or groundwater contamination and to define the extent of the groundwater contamination plumes. An assumption implicit in most of the soil gas analysis studies is that the soil gas values measured at a location are representative of the chemical contamination at that location. Quality assurance experiments conducted during a recent soil gas analysis survey at a waste disposal site have shown that this assumption may be erroneous.

One set of experiments addressed the fluctuation of trichloroethylene (TCE) in soil gas as a function of time. Preliminary results suggested that TCE concentrations in soil gas increased significantly during the morning and early afternoon and decreased in the late afternoon and evening. This increase correlates with changes in temperature during the day. Diurnal experiments were conducted to verify this phenomenon by taking hourly readings in areas having low, medium and large soil gas TCE responses. Significant variation in the TCE response occurred in the hourly analyses, but the 24-h analyses showed no variation.

Another set of experiments was conducted to determine whether soil gas values were representative of soil and/or groundwater contamination. In situ soil gas analyses were conducted in bore holes as they were being advanced. Soil and groundwater samples were collected for analysis. The resulting data indicated that, in a significant number of cases, the soil gas TCE values did not reflect soil or groundwater TCE values. This finding suggests that the flow of soil gas through the unsaturated zone may have an important horizontal as well as a vertical component. This horizontal component may be related to the documented difference in horizontal and vertical permeabilities known to exist in most soil strata.

INTRODUCTION

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The objectives of this study were: (1) to determine whether the trichloroethylene (TCE) concentration in soil gas is a function of time and temperature and (2) to determine whether soil gas values are representative of soil and groundwater contamination.

A relatively new method used to estimate the direction, extent and chemical composition of groundwater involves measuring the concentrations of diffusing chemicals in soil gas near the surface.

With the past few years, soil gas measurements have been used more extensively to define subsurface contamination plumes, particularly for volatile organic compounds. However, the ability of soil gas sampling to detect and delineate groundwater contamination plumes depends on specific properties of the compounds (such as vapor pressure and solubility) as well as characteristics of the site, i.e., soil moisture content, porosity, permeability and grain-

SAMPLING & MONITORING

size distribution).

Soil gas sampling applications are not restricted to detecting and delineating subsurface contamination during the site investigation; soil sampling can be utilized in the cleanup operation.

This paper provides a comprehensive site-specific analysis of the applicability, precision and limitations of a soil gas sampling survey conducted at a waste disposal site.

SITE CHARACTERISTICS

The site investigated is a waste disposal area situated on the upper portion of a peninsula formed by a reverse "s" meander of a river. A manufacturing facility is located on the lower part of the peninsula (Figure 1).



Figure 1 Site Plot Plan for Soil Gas Analysis Investigation

The general site stratigraphy has five major hydrogeologic units. The uppermost unit is an unconfined glacial outwash aquifer which communicates with the river. Within this unit in the western portion of the site is a lacustrine aquiclude. Remnants of this aquiclude were also found in the eastern portion of the site. Underlying this upper outwash aquifer is a substantial glacial till aquiclude followed in order by another glacial outwash aquifer, a glacial till aquiclude and a glacial outwash aquifer which was encountered in one bore hole at an approximate depth of 150 ft below grade.

The major hydrogeologic units encountered in the central portion of the site where most of the disposal activities took place were the upper outwash aquifer and the underlying upper till unit. Within the upper outwash aquifer are lenses of various combinations of fine materials which act as aquitards or aquicludes. These lenses form the aquiclude/aquitard units and are found at many levels and varying areal extents throughout the upper outwash aquifer. The majority of these units seem to be grouped at elevations of 805 and 790 ft (grade elevations range from 811 ft, which is the river elevation, to 835 ft). The two identified aquiclude/aquitard layers exhibit variable hydrological characteristics. This variability is reflected by the fact that at some locations the 805 layer exists, but not the 790 layer, and vice versa. At several locations, the 805 and 790 layers are one unit, while at other locations neither exists. In addition, some locations have layers at other levels within the upper outwash aquifer which do not correlate with either the 805 or the 790 layers.

Figure 2 shows the area where the major disposal activities took place. Three paint sludge pits were located in the area of monitoring well MW-2. A cache of drums was buried just west of MW-2; drums also were placed in a ravine located in the western portion of the site north of MW-3. The central portion of the site, between MW-1 and MW-2, was the location of numerous batch spills and solid wastes disposal activities.



Figure 2 Location of Disposal Areas

SAMPLING METHODOLOGIES

Soil Gas Sampling

The soil gas sampling technique consisted of driving a metal hollow probe to a desired depth in the soil, extracting soil gas with an air sampling pump and collecting the gas in a glass syringe or glass sampling bulb.

The stainless steel sampling probe is 5 ft long, with a $\frac{1}{2}$ -in. outer diameter (OD) and a 0.2-in. inner diameter (ID)(Figure 3). The probe is closed at the tip and perforated above the tip to permit the soil gas entry. A drive plate permits the probe to be hand driven up to 3 ft into the soil. The aboveground end of the probe then is fitted with a 2-ft section which contains a sampling port with a silicone septum. Soil gas is extracted via an air sampling pump.

The probe was evacuated at a rate of 1.5 l/min. A sample was



Figure 3 Soil Gas Sampling Apparatus

drawn from the probe with a 10 cm³ glass syringe equipped with Mininert valves or a 250 ml glass sampling bulb. The soil gas sample was introduced directly into a portable gas chromatograph (GC), HNU Model 301 at the site.

Several precautions were taken to assure the accuracy of the soil gas measurements.

- Prior to sampling, syringes and bulbs were purged with nitrogen and checked for contamination by injecting the nitrogen into the GC.
- Probes were cleaned with tap water followed by a methanol or acetone rinse and a final rinse with distilled/deionized water. The probes were then dried with a propane torch. After cleaning, atmospheric air was drawn and injected into the GC to ascertain the completeness of the cleaning process.
- The silicon septum on the probe was changed after every 10 samples.
- The GC was continually calibrated with chemical standards prepared from 0.1 mg/ml trichloroethylene (TCE), in methanol prepared by Chem-Service, Inc. of Westchester, Pennsylvania, and 10 ppm TCE in nitrogen from Alltech Associates, Deerfield, Illinois.

Water Sampling

Water samples were taken with a 1/2-in. O.D. PVC bailer. The bailer was lowered into the well using a nylon coated rope. Three volumes of water were evacuated prior to sampling. The first two bails collected were discarded to acclimate the bailer to the well water. The third bail was used to rinse the sample containers. When the sample was transferred from the bailer to the appropriate sample container, care was taken not to agitate the sample, thus avoiding the loss of volatile constituents by aeration. Once the wells were sampled, the sample containers were stored on ice.

To prevent cross contamination between wells, all PVC bailers

and ropes were decontaminated with distilled water, followed by an acetone rinse and distilled water rinse. Bailers and ropes then were allowed to air dry. Water samples were sent to a laboratory for chemical analysis.

Soil Sampling

Boring locations were selected to evaluate the stratigraphy of the materials underlying the site, to identify directions of groundwater movement and to determine the presence and areal distribution of two potentially semi-confining layers.

Soil samples were obtained from the surface and at depth intervals of approximately 5 ft with a 2-in. ID split-spoon sampler. Representative portions from each split-spoon sampler were preserved in round, screw-top, airtight-glass jars for physical analysis. Additional portions were collected from surface grade until groundwater was encountered; these samples were preserved in glass jars placed on ice. Each jar was labeled with a boring number, sample number, the depth at which the sample was obtained and the blow count values for each 5-in. interval. To prevent cross-contamination between sampling intervals, the splitspoon sampler was washed with tap water, rinsed with acetone and then with distilled water and allowed to air dry. Soil samples were sent to a laboratory for analysis.

ANALYTICAL METHOD

All soil gas samples and head space samples were analyzed at the site using an HNU 301 GC equipped with a dual flame ionization detector (FID) and a photoionization detector (PID). The column used in this study was 6-ft by 1/8-in. stainless steel packed with 0.1% AT-1000 on 80/100 mesh Graphpac GC from Alltech Associates, Deerfield, Illinois. UHP nitrogen was used as the carrier gas (flow rate 25 cm³/min). The oven was operated isothermally at 150 °C while the injector/detector temperature was maintained at 200 °C. Soil gas samples were introduced into the GC directly from the syringe used to collect the sample or the syringe used to extract the sample from the glass bulb.

Soil and water samples were analyzed in the laboratory using a Hewlett Packard 5880 GC equipped with are Electron Capture detector.

DIURNAL SOIL GAS ANALYSIS

The objective of the first set of experiments was to determine whether TCE concentration in soil gas is a function of time and temperature.

During a survey in the fall of 1985, a test was performed to check the variability of TCE concentration as a function of time. The data indicated that the TCE response increased as the temperature increased during the day and decreased as temperatures decreased in late afternoon and evening (Figure 4).





To verify this phenomenon, a 24-hr soil gas analysis was performed during late spring in 1986. Three locations containing low, medium and high TCE responses were chosen near wells CNI, ASI and MW-17. Sample volumes of 5 to 10 cm³ were collected with a 10 cm³ gas-tight syringe equipped with Mininert valves. A set of syringes was dedicated to each location to prevent crosscontamination. Replicate samples were taken at each location. Time and temperature were monitored closely.

The results of this test showed significant variability between samples throughout the day. However, the diurnal analysis showed no change. The relationship of TCE peak heights and time is shown in Figure 5 for each location.



Figure 5 Log In Situ Soil Gas TCE Peak Height as a Function of Time

Reproducibility

A statistical analysis of the reproducibility of this test demonstrated that for the high TCE responses at well CN1, the reproducibility of this method was 3 to 8%; for the low to medium TCE responses at AS1 and MW-17, the reproducibility was 10 to 35%, which is a measure of both human/instrument performance and the effects of the volume of soil gas pumped.

Replication

Throughout the study it was noticed that the results of consecutive samples demonstrated an increased TCE response after evacuating the probe. This prompted an analysis of seven consecutive soil gas samples at one of the locations used in a previous survey. A plot of this relationship (Figure 6) shows that the rela-



Figure 6 Soil Gas TCE Peak Height as a Function of Replicate Number

tionship is linear. It suggests that there might be an optimal amount of soil gas which needs to be evacuated to obtain a representative sample. Review of similar data having two to three replicates seems to indicate that a linear relationship may exist at other locations; however, these relationships will vary from location to location.

Effects of Soil Moisture

During the course of this study, it was observed that the soil moisture content greatly increase the soil gas TCE response. The initial soil gas analysis survey was conducted shortly before a period of heavy rainfall. Resampling several points on the original survey grid after an extended rainy period resulted in significant increases in the TCE soil gas responses over those recorded during the original survey.

SOIL GAS PROFILING

The objective of the second set of experiments was to determine whether soil gas values are representative of soil and groundwater contamination. Surveys profiling soil gas responses as a function of depth can yield information as to which medium is contaminated; that is, whether the contamination is in the soils or in groundwater(1). Decreases in soil gas responses with depth indicate soils contamination; increases indicated groundwater contamination.

As part of this study, profiling was conducted at several locations. In situ soil gas TCE responses were taken and soil was sampled and subjected to head space analysis. Splits of the soil samples were sent to the laboratory, where the TCE was extracted. After the bore hole was completed and the wells were installed, the groundwater was sampled and analyzed for TCE.

Techniques

Soils were sampled at the surface and at 5-ft intervals until the water table was encountered. At the surface, an in situ soil gas sample was taken as described above. A 2-ft split-spoon sampler was driven into the soil and the resulting sample was split into three fractions. One fraction was dedicated to head space analysis, one fraction went to laboratory TCE extraction, and the final fraction went to the soils laboratory for grain-size analysis. After the soil fractions were obtained, the auger was advanced 5 ft to the next sampling depth.

One variation in the soil sampling technique described above was used during profiling. This consisted of using a 1-in. electrical conduit. Before driving the soil gas probe, it was inserted into the conduit, thereby limiting probe flexing.

Twenty 6-g samples of soil were placed in six 40-ml vials having caps fitted with septa. Three vials were sent to the laboratory for TCE extraction; the remaining three were used for on-site TCE head space analysis. Samples for head space analysis were prepared by shaking the sample vials vigorously for 2 min, allowing them to sit for 5 min and extracting a head space sample using a syringe.

RESULTS

Two methods were used to determine the soil gas TCE response during profiling: (1) in situ measurement of TCE in the soil gas and (2) head space analysis of an extracted soil sample. Figure 7 shows a plot of the head space TCE responses as a function of the in situ TCE responses. One would expect a correlation to exist between the head space TCE response and the in situ TCE response measured at the same location and depth. However, Figure 7 shows that this relationship does not exist. This result probably can be attributed to the disturbance of the soil sample during the sampling and sample preparation process.

In addition, a review of the in situ/head space data revealed no pattern where one method of soil gas measurement yielded higher TCE responses than the other. In some cases the in situ TCE responses were larger than the head space TCE responses, and vice versa. It was thought that grain size could be a contributing factor. With extracted soil samples, soil gas trapped by finer material could yield higher head space responses than the in situ responses. With



Figure 7 Log Head Space Soil Gas TCE Peak Height as a Function of Log In Situ Soil Gas TCE Peak Height

coarse grained samples, TCE would volatilize more readily during the sample preparation process, resulting in lower head space responses.

In situ and head space responses were plotted as a function of the amount of fines in the soil sample (Figures 8 and 9). In both cases, no relationship could be established between soil gas responses and the amount of fine material in the soil samples. Again, these results probably reflect factors associated with sample disturbance. The soil grain-size distribution is an important factor in the determination of contaminant soil gas concentrations, but probably only when considered along with in situ soil moisture, permeability, porosity and density. In general, the authors feel that in situ soil gas measurement is more representative of actual soil gas conditions than head space analysis methods.

A summary of TCE data as a function of depth is presented in Table 1. This table includes in situ soil gas responses, soil TCE concentrations, TCE concentrations in the groundwater and predicted soil gas responses based on the measured soil and groundwater TCE concentrations. At locations B, C, and CN1, the predicted soil gas TCE responses are significantly larger than the in situ soil gas TCE responses measured. This difference is even more significant for locations B and C where no soil TCE concentration data are available. Soil TCE concentration data would increase the predicted response even more. These results could reflect dispersion and/or horizontal movement of the soil gas away from the source. The reverse situation seems evident when reviewing the data from locations M1N1 and M1S1. At these locations the in



Figure 8 Log In Situ Soil Gas TCE peak Height as a Function of Percent Fines





situ soil gas TCE response is greater than predicted, indicating that soil gas TCE is being transported to the sampling location from another location. This suggests that the flow of soil gas through the unsaturated zone may have an important horizontal as well as a vertical component. This horizontal component may be related to documented differences in horizontal and vertical permeabilities known to exist in most soil strata.

 Table 1

 Summary of TCE Data as Function of Depth

Location	Sample Dopth (ft)	Log Insitu Soil Gus TCE Peak Height	Soil TCE (mg/Kg)	Groundwater TCE (ug/L)	Log Predicted Soil Gas TCE Paak Heights ^a
ъ	1.0	1.38	ъ	46,000	5.03
Ð	6.0	1.96	5	46,000	5.03
с	1.0	3.80	ь	25,000	4.77
с	8.0	2.11	ь	25,000	4.77
с	10,5	2.24	b	25,000	4.77
с	14.5	1.75	•	25,000	4.77
CNI	1.0	231	<0.05	945	2.60
MINI	1.0	2.71	<0.05	<50	-0.24 to 1.45*
MINI	7.0	1.62	<0.05	<50	-0.24 to 1.45
MINI	9.0	1.78	<0.05	<50	-0.24 to 1.45
MISI	1.0	2.97	<0.05	<50	-0.24 to 1.45
M151	3.0	2.92	⊲0.05	<50	-0.24 to 1.45

 Soil gas response predictions based on measured soil and groundwater TCE concentrations were calculated using the methodologies of Lyman, et al. (1982) (2).

No TCE soil measurements available.

⁴ The range of the predicted soil gas TCE peak heights was established assuming that minimum TCE values were 1 mg/kg and 1 mg/L for soil and groundwater, respectively, and meximum values were 50 mg/kg and 50 mg/L, respectively.

CONCLUSIONS

The results of the experiment suggest that the interpretation of soil gas data may be more complicated than previously thought. On the other hand, the results suggest that more information may be obtained from soil gas collection and analysis activities.

The following observations were made during the course of this study:

- During diurnal testing, hourly soil gas TCE sampling showed significant variation between samples, but the diurnal trend exhibited no change over the 24-hr sampling period. The results were the same for tests conducted at three locations having low, medium and high soil gas TCE responses.
- Replicate sampling at surface soil gas sampling locations showed a marked increase in TCE response as more replicate samples were taken. This relationship seems to be linear and suggests that there may be an optimum volume of soil gas which should be evacuated before sampling.
- The presence of soil moisture seemed to enhance the soil gas TCE response.
- No relationships existed between head space measurements of TCE in soil samples taken from the in situ sampling locations and the in situ measurements of TCE. This probably is due to the disturbance of soil structure during sampling.
- No relationship could be established between head space TCE responses in the soil gas and the amount of fines in the soils. This also was true of the in situ TCE responses as a function of the percent fines. Again, this may be due to disturbance of the soil sample while conducting a grain size analysis. This finding suggests that the in situ soil moisture content, permeability, porosity and density are key parameters in determining the volume of soil gas which can exist in a given soil pore space.
- Comparison of in situ soil gas TCE responses with TCE soil and groundwater concentrations showed significant differences between the amount of TCE expected in the soil gas and the amount actually measured. Cases were observed where the soil gas TCE response was greater than expected and less than expected. These results suggest that a horizontal component of soil gas movement through soil pore spaces may be significant, particularly since it has been documented that most soil strata have greater horizontal permeability than vertical permeability.

The experiements conducted and the observations made during the course of this study were auxiliary to the soil gas analysis survey conducted at the waste disposal site and are preliminary in nature. More work is required to verify these findings and learn more about the nature of the movement of soil gas in soil pore spaces. The results of this study are helpful in planning future soil gas analysis surveys and suggest that more information may be available to the researcher through the use of this technique.

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Field Quality Assurance: A System for Plan Review, Tracking and Activity Audit

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ABSTRACT

The purpose of this study was to develop a process for planning and executing field sample collection undertaken in support of Superfund investigations in U.S. EPA Region IX. Procedures are described for preparing Sample Plans which detail study objectives, rationale for sampling, analytical resource requirements and field methodology, incorporating Agency protocols. The plans also serve as a basis for audits of field activity. Criteria have been developed to review and evaluate field work quality.

The procedures have evolved over a 3-year period, during which approximately 150 site-specific Sample Plans have been reviewed and over 15 field audits have been conducted in California, Arizona and Nevada. Participants in the system include contractors, cooperating state agencies and the U.S. EPA. Important elements of the process are training, communication, automated tracking systems, consistent review and followup to correct deficiencies.

Details of the system will be discussed, and field examples of the process will be shown. The findings demonstrate the importance of management overview and audit in order to achieve valid data and effective resource utilization.

INTRODUCTION

Nationwide, the Superfund program has been expanding rapidly and this pace will increase with the anticipated reauthorization. In U.S. EPA Region IX, many organizational units and contractors participate in the process of site assessment and cleanup. One unit (the Superfund Programs Branch) bears ultimate responsibility for assuring that a comprehensive schedule is established to carry a given site from the point of discovery to cleanup. Field operations and associated contractor support are the responsibility of the Field Operations Branch. Since a number of activities in several organizational units may occur simultaneously, it is essential to coordinate and track the phases so that funds will be spent effectively, milestones will mesh and contamination threatening the public health and environment will be mitigated expeditiously.

The process of site assessment involves two major technical arenas: field surveys (including monitoring and sample collection) and laboratory analyses. All activities must be planned in advance, staged and the results interpreted to accurately assess contamination characterization at a given geographic location.

In the laboratory phase of the assessment, the analytical protocol and the data review/validation process follow well-established and accepted methods. Generally, historical compilations of laboratory results using the standard methodologies exist so that specific findings may be contrasted with theoretical expectations. With many individual laboratories and researchers using standard methodology, the statistical evaluation of outcomes can be based on a relatively large population sample.

These perspectives and data bases are not available for most of the field work associated with hazardous waste sites. Procedures for the planning and execution of field work have not been standardized to any substantial extent. The purpose of this study was to develop an effective, orderly procedure to plan and audit field work, with a goal of reducing the opportunity for error. This paper is based upon findings gathered from reviews of more than 150 plans and audits of approximately 10% of these plans.

Typically, there are limited and specific applications for field studies undertaken in support of Superfund:

- Regulatory activity—to establish U.S. EPA authority and to permit U.S. EPA involvement
- Enforcement evidence gathering—to demonstrate a violation of the law
- Investigation—to gather information on the type, extent and dispersion pattern of contamination
- Remedial project decision-making—this is the most demanding use of data

Usually, this last application has the greatest number of associated consequences—both economic and social. Design and implementation of multimillion-dollar remedial programs are based upon analytical findings. These solutions are expensive and the prospect of being wrong is untenable for the welfare of the affected population as well as for budgetary reasons.

For any of these applications, the attributes of the high quality data being sought include:

- Validity—the concentrations and identities of the pollutants fall within acceptable confidence limits, or if they do not, the actual confidence limits can be stated
- Accuracy—the assessment of contamination closely reflects the situation originally being investigated
- Defensibility—the evidence must be able to stand up in court, i.e., maintain credibility under intense scrutiny by experts in an adversarial setting
- Reproducibility—the results must be achievable by another researcher using comparable equipment and methodologies

Seven or 8 years ago, there was mostly art in the application of state-of-the-art hazardous waste sampling. Contaminants were measured usually in the ppm range. Today, however, it is routine to measure contaminants in the ppb and ppt ranges of concentration. With this increased sensitivity in analytical quantification limits has come a parallel need for corresponding sensitivity in the execution of the field work.

SAMPLE PLAN

The device developed by the Toxics and Waste Management Division, U.S. EPA Region IX, to induce precision and accuracy in hazardous waste field work planning is the Sample Plan.

Sample Plans are required of:

- All U.S. EPA sampling done in support of hazardous waste programs
- All contractors doing similar work for U.S. EPA Region IX
- All cooperating state agencies
- All potentially responsible parties doing field work under a Consent Agreement or other enforcement arrangement with the U.S. EPA

Sample Plans serve dual purposes. They are used for:

- Justification for expenditure of laboratory resources—the U.S. EPA Region IX (CA, AZ, NV, and HI) spent \$1.4 million last year in hazardous chemical waste analyses alone; the cost per sample for organic hazardous substances has averaged over \$1,000.
- Field quality assurance—the Sample Plan document is used by the field team as a blueprint of the field work (this plan may be supplemented by a specific compendium of standard operating procedures); it is used by the field auditors as a description of what should take place during the field work.

The Sample Plan contains the following elements:

- Background information (usually the Preliminary Assessment)
 Objective of sampling effort
- Rationale for sample locations, number of samples and analytical parameters
- Maps
- Analyses to be performed
- Methods and procedures Sample collection techniques Equipment decontamination
 - Disposal of contaminated materials
 - Sample containers
 - Sample preservation
 - Sample packaging and shipment
 - Sample documentation
 - Quality assurance samples
- Site Safety Plan

The plan usually contains a bibliography of pertinent standard operating procedures. If the Sample Plan references another document such as a quality assurance project plan or a special analytical methodology, it should be included for ease of review.

Once the Sample Plan has been written, it is reviewed by a qualified organizational unit separate from the Plan's author. The review focuses on the Plan's logic flow from the opening premises to the execution. The reviewer refers repeatedly to the Plan's objectives, asking whether the hypotheses will be confirmed and whether the planned work will achieve the objectives. Field work does not commence until the Sample Plan adequately ensures that the field work to be undertaken will achieve the desired objective.

Training is an essential element in the process. Formal training sessions are conducted by the U.S. EPA whenever there are new teams coming into the system (these may be new contractors or new state agencies). As a followup to the training, the U.S. EPA schedules a field audit when the newly-trained team commences field work for the first time after the training session. This field audit has proven to be a cost-effective expenditure of resources; it is much easier to work with the team, showing them how to perform the work correctly at the beginning, than it is to reassess the work after the fact and attempt compensations.

It is prudent to avoid setting up a system which has minimal planning and focuses on resampling as a routine occurrence. The cost of laboratory analyses for hazardous substances is too high. Even more costly is the potential need to redeploy specialized sampling equipment (such as drill rigs), special on-site monitoring equipment and mobile laboratories.

The logistics of planning and staging field operations require specialized tracking systems to assure that all the elements of the project mesh. Currently, the U.S. EPA Region IX administrative system is comprised of several separate organizational units including contractors, and there are a large number of projects in the system. Sample Plan reviews at times are complicated, with several iterations of a plan going back and forth from reviewer to author.

Once the field work is in progress for a given project, several laboratories may be involved in sample analyses. To maintain project momentum, successful completion of each step must be tracked to enable all critical efforts to be accomplished. Computerized tracking has proven to be the most versatile method. Inherent in the concept of tracking is the need for periodic review of progress and deliberate action to correct any problems in the complex system.

Fig. 1 shows a diagram of the flow of a sampling event from the initial determination by the project officer that a sampling study is necessary with certain data objectives through to the production of validated data. Decision points are shown. Review must be timely so that overall project decisions and deadlines can be achieved.



Observations made during the performance of field work prove that without a blueprint for the field work actually present onsite, the work will proceed with shortcuts and other modifications rendering the approved Sample Plan meaningless as a description of what actually occurred in the field. This can cause errors in interpretation when the results of analyses are provided. It further has the potential to cause misdirection of resources to correct site problems (i.e., money may be spent erroneously and the real problems may persist uncorrected). However, field judgment is essential to determine whether necessary modifications still achieve study objectives.

FIELD AUDIT

The field audit process is outlined in Table 1. Checklists are developed, specific to each sampling episode, and based upon the investigation's Sample Plan.

Table 1 The Sampling Field Audit Process

- Review and evaluate Sample Plan for completeness and adequacy. Ι.
 - A. Sampling objectives.
 B. Rationale for sample locations, number of samples, and analytical parameters.
 C. Methods & procedures.
 1. Sample collection. в.

 - Equipment decontamination. 2.
 - 3. Sample containers.
 Sample preservation.
 Sample shipment.
 Sample documentation.

 - 7. Quality Assurance/Quality Control (OA/OC) samples.
- II. Develop audit checklists based on Sample Plan.

A. Checklist for sampling at each sampling point. B. Checklist for overview of the sampling event.

- III. Conduct audit.
 - A. Field work
 - 1. Document all field work with checklists, notes and photographs. Audit comple
 - Audit <u>complete</u> sampling process at one or more sample points (more = better). 2.
 - B. Interview samplers (after field work is completed).
 Review overall sampling process.
 Discuss problems to changes can be initiated.
 Copy complete sampling field notes for the entire entry is even to be an even.
 - copy complete sampling field notes for prior sampling event or events (Check for consistency of field work
- IV. Review and evaluate field work for completeness and adequacy.
 - A. Will the sampling event meet the Sample Plan objectives? ment)?
 - Are the sampling procedures adequate (professional judgm Will the sampling procedures bias the data in a positive or negative direction? c.
- Compare the actual sampling event to the Sample Plan.
 - A. Was the Sample Plan followed?
 - B. Are discrepencies significant?

over time).

VI. Write the report.

- A. Sample Plan review.
- Sample riam Lorange Field work review. Comparison of field work with Sample Plan. Validity statement as to usability of data generated by this sampling effort as a result of procedures used in the field. D.

Table 2 is a typical checklist for overview of a groundwater monitoring well sampling event. The checklist is tailored to provide a summary of the points for scrutiny. It should be noted that for east of field operation, the details are compressed onto a single sheet printed on both sides. The observation points are arranged so that they follow the flow of the sampling effort as described in the Sample Plan.

Table 3 shows a Summary of the Field Audit Findings during a groundwater sample audit. A copy of this summary is given to the field team after the exit interview by the auditor. The benefit of providing immediate feedback is that problems may be corrected promptly.

Table 2 Sample Audit Checklist

Typical Sample Audit Checklist (Ground water Monitoring Well) (One Per Sample Location)

Aud	itor: Date Audited:	WELL #
Dat	e Purged: Date Sampled:	
Sam	plers:	
1)	Was the well locked?	(Y/N)
2)	Is the well vented?	(Y/N)
3)	Is the well clearly labeled?	(Y/N)
4)	Does the integrity of the surface seal appear adequate?	(Y/N)
5)	Was Depth-to-Water (DW) measured prior to the initiation of	purging? (Y/N)
	What was the increment of measure?	
	What device was used to measure DW?	
	Was the sounding equipment decontaminated after use?	(Y/N)
6)	What equipment was used to purge the weil?	
7}	Where in the water column was the intake for the purge syst	em placed?
	At the well screen (top middle bottom) Just below t	he surface
	Other	
8)	Was the purging equipment decontaminated prior to purging?	(Y/N)
	How was the purging equipment decontaminated?	
9)	Was the Purge Volume calculated prior to purging?	(Y/N)
10)	Was the Purge Volume measured during the purging?	(Y/N)
	How?	
1)	Was a Discharge Rate measured during the purging?	(Y/N)
	How?	· · · · · · · · · · · · · · · · · · ·
3)	What volume of water was evacuated?	
4)	How many Casing Volumes?	
5)	What was the purge schedule?	
16)	How was the purged water disposed of?	
L7)	What was the time period between the purge and sampling at	this well?
18)	Was Depth-to-Water (DW) measured just prior to sampling?	(Y/N)
	What was the increment of measure?	
	What device was used to measure DW?	
	Was the sounding equipment decontaminated after use?	(Y/N)

FIELD JUDGMENT

The Sample Plan is not an inflexible document. There is no method for authors of the plan to predict with unerring certainty all the real field conditions. It is essential that the goals and objectives of the investigation be stated clearly so that samplers may have the leeway to substitute technologies and decisions which do not adversely affect the overall objectives.

The Sample Plan is neither a substitute for field judgment, nor a blueprint for auditor judgment. In fact, the Sample Plan enhances both judgment and audit, because field personnel can continually refer to the stated objective and question whether the activity as described will achieve the desired objective. If the answer is "no," then the effort must be modified, and both auditor and sampling team must perceive the adequacy of the modification to achieve the objectives.

TYPICAL FIELD DECISIONS

These field situations are given to illustrate the types of decis-

Table 3

Summary of Field Audit Findings During a Groundwater Sample Audit

SAMPLE AUDIT (Ground Water Monitoring Nell): OVERVIEW

	Auditor: Date Audited:		_
	Pacility Repsi		
1)	When was the purge sequence established?		
2}	How was the purge sequence established?		
		····	_
3)	When are Depth-to-Water measurements taken?		
	- <u></u>	·····	
4)	Are Depth-to-Bottom measurements taken?	(Y/N)	
5)	How frequently?	<u> </u>	
6)	is the 'sounder' calibrated prior to each measuring e	went? (Y/N)	_
	Ho-/?		
7)	From where in the water column is the sample collecte	17	
9)	Is the Q/C information on the sample containers evail	able? (Y/N)	_
10)	What information is kept in field log books?		_
11)	Are Chain-of-Custody records kept for each sample?	(Y/N)	_
12)	Are Chain-of-Custody seals placed on each sample cont	ainer? (Y/N)	
13)	Does a Sample Analysis Request sheet accompany each a	ample? (Y/N)	
14)	Are duplicate samples collected?	(¥/N)	
	Rov frequently?		
	Now are the duplicate sample points selected?	<u></u>	
15)	Are travel blanks collected?	(Y/N)	_
	Nov frequently?		
16)	Are equipment rinsate/methods blanks collected?	(¥/N)	
	Hor frequently?		_
17)	Are field blanks collected?	(¥/N)	
	How frequently?		
181	What is the accurse of unter for the black samples?		

19}	Parameter	1/Type of Container	Field Handling and Preservation	Camente
	VOA			
	TOK			
	TOC			
	Extractables		<u></u>	
	Anions & Cat-			
	Metala			
	RAD			
	Coliform			
	Cyanide			
	Cr+6			
	Sulfides	<u> </u>		
	Nitrates		. <u></u>	
20) 21)	How frequently Which laborato	are the samples shippe ries are being used for	d7	.7
	ADDITIONAL COM	MENTS:		

ions which might be made during a sampling event. Sample team members as well as auditors must be experienced enough to judge

whether the field situation encountered warrants a deviation from the Sample Plan to achieve the objectives of the study. The auditors must also be able to evaluate whether any perceived deviations from the approved Plan procedures actually constitute significant variation.

Example I

The purpose of a recent investigation was to collect dry sediment samples for the analysis of pesticides. The sample location was a dried pond in a low spot on the property. In the Sample Plan, the procedure specified sampling the upper 2 in. of sediment. However, in the field, the sediments in the dried pond were unexpectedly clay material with cracks 8 to 10 in. in a crazy-quilt pattern. Additionally, the samplers were limited by the number of samples which could be collected and processed through the laboratory. Seven sample points had been specified in the Plan.

A field decision was made to collect six samples from the upper 2 in. of clay. The seventh sample was collected at a depth of 2 in., and another sample was collected by tearing out a chunk of clay and sampling along the base of the crack. This seventh sample was at the lowest point in the dried pond and was the most likely to have incorporated contaminated sediment particles.

A second decision was that if the analyses results showed the samples along the crack exhibiting significantly increased concentrations of pesticides, then another phase of sample collection would be scheduled to include additional depth samples.

Example II

Monitoring well sampling was planned at another site. There were a number of wells to be sampled in a limited time; the order of sample collection was specified as volatiles, semivolatiles, TOC, TOX, phenols, metals, anions/cations and finally radionuclides. Some prior knowledge existed about the concentration found of the various contaminants at the different well locations (volatiles and certain metals had been detected at some wells). All samples collected were to be split with the property owner, meaning that double volume was required.

When the well at one location was purged, it was observed to have a very slow recovery rate. Several days recovery would have been required in order to collect sufficient volumes to enable analyses of all the constituents. A field decision was made to change the order in which the sample containers would be filled after purging: first, volatiles (as in original plan); second, metals; third, TOC and TOX. After the well recovered, semivolatiles and anions/cations were to be collected. The remaining analyses were dropped because the volume after recovery was not sufficient to include them. It was a management decision to spend 5 hours rather than 3 days sampling at this location.

Example III

In a dioxin sampling study described in another section of these *Proceedings*,' the Sample Plan called for conformity with National Dioxin Study protocols. One requirement specified that soil be collected with a 4-in. tulip bulb planter.

Field trials showed compacted soil (which the tulip bulb planter could not penetrate) and unconsolidated material in sedimentation pathways (i.e., loose soil and gravel) which would not stay together in a core as intended. The problem had been anticipated. Garden trowels with measures graduated in inches had consequently been included in the sampling gear. These trowels were used to collect an equivalent sample volume (the uppermost 4 in. of soil) at each sample location.

FIELD EXPERIENCE AS A PREREQUISITE FOR AUDITORS AND REVIEWERS

Observations of the process have demonstrated the liabilities of

employing field auditors with little pertinent field experience. Deviations from the approved Sample Plan may be noted, but the auditor has no perspective within which to evaluate the significance of the perceived deviation. Thus a minor substitution of sampling tools may be noted, and the significance of the event cannot be distinguished from something as major as the lack of adequate decontamination procedures between two sampling locations where the same sampling tool was used or the substitution of an inapproproate drilling method during installation of a monitoring well.

Field experience is also important during the independent review of the plan by knowledgeable reviewers. Otherwise there is the possibility that independent, non-approved operating procedures inadvertently may become incorporated into the protocols with the resultant possibility of not achieving the desired data quality objectives. An independent qualified reviewer is in the position to compare the written plan with the objectives and answer the question, "Does this procedure enable the gathering of evidence to support this goal?"

Currently, field audits of Superfund projects in U.S. EPA Region IX are performed on approximately 10% of the total sampling projects. The auditors are experienced field staff who are trained in field sample collection and who could serve as expert court witnesses in the event of an enforcement challenge.

The report of the field audit is a memo stating:

• Whether or not the Sample Plan was followed substantially

- The nature and significance of any observed deviations
- Whether or not the sample effort was valid to meet the study objectives

Audit results receive appropriate and timely followup to correct identified problems within the monitoring systems. When generic problems with a specific group are found, immediate management attention is devoted to solve the difficulties through training, discussion, reorientation of personnel or other appropriate remedies.

CONCLUSIONS

It has been found in the Sample Plan review, tracking and audit system that the described process helps organize the various components of the Superfund site field project. A number of teams can be deployed to deliver their own expert contributions, and the entire project coalesces and provides needed answers on the extent and type of contamination. The field audit supports the process by verifying that the sample objectives have been met and that any significant deviations have been noted and corrected.

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The Importance of Field Data Acquisition in Hydrogeologic Investigations at Hazardous Waste Sites

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ABSTRACT

Hazardous waste site investigations and remediations are dependent on the sampling data collected during field activities. These data are the foundation of all engineering remediation design. Field data collected that are not representative of sampling media can result in inappropriate decisions, reduced efficiency in a remedial measure of even the selection of an ineffective technique.

Because groundwater impact is often a major concern at hazardous waste sites, the acquisition of the geohydrologic information is of the utmost importance in site remediation decision-making. Decision-making in remedial design based on erroneous data will inherently slow the cleanup of hazardous waste sites throughout the country.

Close coordination between scientists and engineers during the Remedial Investigation is essential to design a field program that will supply the necessary data to evaluate the remedial options applicable to the site.

INTRODUCTION

The identification, prioritization and remediation of Hazardous Waste Sites are primary objectives of CERCLA. In the assessment of Hazardous Waste Sites, the acquisition of field data is extremely important to the decision-making process. Information collected during site identification and prioritization often is used to plan and implement the Remedial Investigation and, subsequently, to characterize the fate and migration of the waste and the associated risk to public health and the environment. Remedial Investigations are conducted to define the extent of the problem and provide adequate information to identify the appropriate remedial technology.

Since the authorization of CERCLA, it has become apparent that groundwater contamination is the predominant problem associated with many hazardous waste disposal sites. Since the enactment of this legislation, the installation of groundwater monitoring wells has increased dramatically. The National Well Water Association reports that 39,084 monitoring wells were installed at hazardous waste sites in 1983, compared to 121,294 monitoring wells installed in 1985.1 Guidance documents have been developed by Federal and state agencies, consultants and professional societies to standardize the selection, installation, construction and sampling of groundwater monitoring wells. Many technical papers have identified inherent problems with existing technology and statisticians have shown that human error can affect chemical analysis. Evaluation of the hydrogeologic environment, through data collected and interpretation, has been and will continue to be an area that will come under much scrutiny by scientists and engineers in the assessment and remediation of hazardous waste sites.

The following text discusses two commonly used groundwater remedial technologies and how the collection of the field data can affect the decision-making process during remediation. It also recommends an approach that will increase the efficiency of the investigations and remediation of groundwater contamination.

GROUNDWATER REMEDIATION

The ideal approach to the remediation of contaminated groundwater is to remove or neutralize the contaminant source and capture and treat the affected groundwater. Unfortunately, removing the source is rarely the most economical or desirable approach. Feasibility studies are conducted to select the most cost-effective remedial technology that protects public health and the environment.

These studies are largely dependent on the data base developed during the Remedial Investigation. Two groundwater remedial options frequently evaluated in feasibility studies are contaminant barriers and groundwater control, or pump and treat.

In contaminant barrier remediation, a cap is commonly installed over/around the contaminant source area to minimize leachate generation and retard migration, while vertical walls are installed to a specified depth and tied into a horizontally continuous unit, referred to as a key-in unit. This key-in unit must be a confining layer and be of sound structural and hydraulic integrity so a good seal between the vertical wall and the key-in unit can be obtained. The vertical walls typically are composed of a combination of bentonite, cement and natural fill. Contaminant barriers are not intended to reduce contamination but may effectively capture contaminated groundwater and minimize the spread of contamination. In many cases, the barrier system will require some type of upgradient groundwater diversion to prevent excessive hydraulic gradient buildup.

Groundwater control/pump and treat is also an increasingly common approach to groundwater remediation. Contaminated groundwater, once extracted, can be treated to predetermined contaminant concentrations and released. To enhance this remediation, the treated water can be injected or released upgradient of the existing recovery system to recirculate and help flush the contaminated portion of the aquifer. It is important to note that the treated water must be released within the cone of influence of the recovery system. Recent studies have shown that the addition of nutrients to the treated water, prior to the release through the injection well, can accelerate the biodegradation of certain hydrocarbons.²

Both of these technologies require an extensive data base to

evaluate these options. This data base is generated during the remedial investigation and is extremely important for a successful remediation.

DATA BASE

Remedial Investigations are typically large-scale multi-disciplinary studies aimed at addressing several overall objectives. Two major objectives of Remedial Investigations, in which groundwater contamination is the focus, are the characterization of the hydrogeologic setting and the determination of the contaminant distribution profile.

The hydrogeologic data base is comprised of subsurface information available through regional and local maps and existing borings. Regardless of the amount of regional information, collecting site-specific information always is required. Collecting this information is the primary objective of the Remedial Investigation. There is no mathematical formula to determine the necessary number of data points to adequately define the hydrogeologic environment. The number of wells and borings is dependent on the complexity of the strata, the type or types of aquifer(s) and the variety of chemical compounds found at the site.

Four common examples of aquifer systems are sedimentary, alluvial, glacial and igneous/metamorphic. A brief description of some specific variables is identified for these four systems.

Sedimentary environments, generally, are the least stratigraphically complex of the four but may, depending on the sequence, contain several water bearing units. In the multi-unit case, the number of monitoring wells installed to define water bearing units may exceed the number of wells required to define the aerial contaminant distribution. This is especially true of contaminants that have specific gravities in excess of 1.0.

Alluvial aquifers deposited by rivers and streams often will require extensive permeability tests and grain size analysis to determine hydraulic conductivities throughout the deposit.

The average grain size found in alluvial deposits can vary considerably and may vary from fine silt (found in flood plains) to coarse sand and gravel (typical of alluvial fans). The data collected prior to and during the drilling activity are extremely important in the evaluation of contaminant pathways through alluvial aquifers.

Hydraulic conductivities in glacial aquifers can vary widely. Grain size and grain sorting are important parameters in the data base. Depending on the type of deposit, grain size can be quite uniform (as in an outwash plain deposit) or heterogeneous (as in glacial moraines). Glacial features can be identified using topographic maps and visual reconnaissance. Subsurface stratigraphy, however, generally can be confirmed only by drilling.

Most igneous and metamorphic rocks have extremely low hydraulic conductivity, and groundwater movement is controlled by secondary porosity (i.e., fractures and joints). The data base for hydrogeologic investigation in igneous and metamorphic rock includes regional fracture information obtained from aerial imagery. The effectiveness of monitoring wells installed in bedrock is extremely dependent on the interception of fractures. Predominant flow patterns often are linear in fractured bedrock and frequently are oriented parallel to regional strike of larger scale features (folds and faults).^{3, 4}

These four types of aquifer systems can include unconfined as well as confined groundwater which can add to the complexity of the evaluation. Definition of the hydrogeologic regime is essential to the successful design and construction of contaminant barriers and groundwater control systems.

It is also essential to develop a suitable data base in chemical contamination throughout the subsurface. The chemical data base is generated from analysis of samples collected from the contaminant source areas and migration pathways (e.g., groundwater, surface water, air, soil). To assess the migration patterns of contaminants, a thorough understanding of the physical properties of the individual contaminants is needed.

Variations in the chemical data base can be caused by the drilling technique, well construction and sampling. Selecting a drilling technique and well construction specifications should take into account the potential effects of the drilling fluid, grouts and well construction material. The sampling data base should include more than one round of sampling and sufficient QA/QC samples (blanks and duplicates).

The generation of the chemical data base, in conjunction with the hydrogeologic information, must be carefully planned and implemented so the selected remedial technology will be both appropriate and effective.

Two examples are presented to illustrate how the collection of field data can adversely affect site remediation.

EXAMPLE #1

This site is situated on a fine grain glacial outwash formation. The strata consists of fine sand and silt varying in thickness from 10 to 60 feet. The water table was within 20 ft of the ground surface. An undetermined amount of hydrocarbon fluid (less dense than water) was being released into the subsurface.

A preliminary set of monitoring wells was installed into the unconsolidated deposits with 10-ft screened intervals. These wells were single well installations designed to intercept the water table. A floating hydrocarbon layer was detected in one of the wells; however, the lateral boundary of the hydrocarbon layer could not be determined. Subsequently, additional monitoring wells were installed to provide data to be used for site remediation. Following the installation of the additional wells, a map identifying the lateral limits of the hydrocarbon layer was developed. A recovery system was installed that consisted of the installation of one large diameter well designed to induce a cone of depression (with a submersible pump) to draw in the hydrocarbon layer. A second pump, or scavenger pump, would then collect the hydrocarbon layer. The remediation attempts were largely unsuccessful. The surrounding monitoring wells began to show increasing volumes of hydrocarbons with little or no hydrycarbon fluid in the recovery well during operation.

Review of the study revealed the absence of very important field data which made calculations of hydraulic conductivity values impossible and resulted in the selection of an ineffective remediation. During the installation of the preliminary wells, too few overburden samples were collected to define the average grain size. Screening intervals were not located to monitor the water table. The installed screen slot size was too large and allowed excessive sedimentation, and, in some cases, sediment buildup extended upwards to the seasonal high water table. The second set of wells also used the same screen slot size and had the same sedimentation problem, although to a lesser extent. Screening intervals were longer and positioned to intercept the water table. The recovery well was designed based on these wells. However, in situ permeability tests were not performed and, to the author's knowledge, no type of aquifer pumping test was performed to delineate the cone of depression.

During the drilling program, borehole permeability tests should have been conducted to ascertain the permeability of selected strata. Grain size analysis also would have provided valuable information for the screen slot size and filter pack selection. Finally, an aquifer pumping test would have provided transmissivity values necessary for determining the appropriate recovery system.

EXAMPLE #2

A site located on a sand and gravel aquifer received and permitted the disposal of liquid hazardous waste onto the ground. The waste percolated to the groundwater and began to migrate off-site. The degradation of the groundwater and its potential impact on residential groundwater wells downgradient prompted an investigation. The objective of the investigation was to gather the necessary field data to plan and implement site remediation.

The immediate remedial option was determined to be the installation of a slurry wall extending to the bedrock surface. Borings were advanced until refusal into glacial till. The till was assumed to be continuous and relatively impermeable. At the one location where bedrock was encountered, the surface was found to be highly fractured.

The result of this one boring prompted further site characterization of the bedrock integrity. The subsequent study found that the bedrock sloped and the till layer thickened. The assumption that the till layer extended horizontally proved to be correct. However, a redesign of the slurry wall was necessary due to the increased depth, and integrity of the bedrock surface.³

Here the key-in unit was the bedrock, and the initial study had only one boring into the bedrock. The subsequent study enabled better definition of the till layer and bedrock surface, which allowed a redesign of the slurry wall. If the original study had included better definition of the bedrock, the second evaluation may not have been necessary.

These two examples demonstrate that collecting field data is extremely important in hydrogeologic investigations and remediation. Managers, engineers, scientists and regulatory officials all must be aware of the limitations of the field data collected and how that data will affect the decision-making process and, ultimately, the remediation effort.

INCREASING THE EFFICIENCY OF FIELD DATA COLLECTION

The author has observed numerous occasions where the data base compiled during the Remedial Investigation was not sufficient to evaluate the remedial options. In some cases, additional studies or followup data collection were unavoidable. However, in many cases, the engineers and scientists developing the feasibility study did not become involved in the project until after the remedial investigation, and similarly, the remedial investigation coordinator may not be involved in theoretical applications regarding the remedial options. Remedial investigation field data should provide the appropriate type and amount of data to enable the evaluation of all applicable remedial options.

The logical approach to designing a successful program that will support the Feasibility Study involves first identifying which remedial options might apply to the site and then designing the data collection program to provide the required information. Without this foresight, field data will be collected which may or may not provide all the necessary information to evaluate the appropriate remedial technologies.

If the field program is initiated without knowing which remedial techniques are being considered, the following approach will maximize the likelihood that the data base will be sufficiently complete to support the subsequent Feasibility Study.

When drilling in unconsolidated formations, split spoon samples usually are collected every 5 ft and at all strata changes. For example, in the unconsolidated glacial formations, sand and gravel lenses are common.⁶ When collecting samples every 5 ft, these lenses can be missed even by an experienced field geologist. These lenses, which may have higher horizontal permeabilities, can provide more rapid and concentrated attenuation of contaminants.⁷ If the screening interval does not intercept these lenses, the contamination may be detected at a lesser concentration or even be missed altogether, depending on the density and solubility of the contaminants. Therefore, it may be prudent to collect continuous split spoon samples at selected wells. Representative overburden samples from the screened horizons should be submitted for grain size analysis to confirm field classifications.

Proper monitoring well screening intervals depend not only on the strata, but also on the objectives of the investigations. In a preliminary investigative situation, a fully screened monitoring well may be more appropriate to provide an overall picture of the groundwater quality. For investigations that likely will spawn a comprehensive Remedial Investigation, nested wells provide the hydrogeologist with a much better data base to evaluate the hydrogeologic environment and the characteristics of the contamination migration.⁴ Regardless of whether the investigation is at the preliminary stage or the advanced remedial level, field analytical screening of split spoon samples with portable field monitoring instruments can enhance the likelihood of identifying contamination zones during the drilling activity. Monitoring well screening intervals then can be selected to intercept the zones of interest.

Field analytical screening of split spoon samples can be beneficial in selecting monitoring well screening intervals. However, field analytical screening should not be the entire basis for the selection of monitoring well screening placement. Therefore, it may be advisable to install nested wells to screen the entire length of the unconfined water table, especially in cases where the contaminants are soluble in water or more dense than water. This approach toward monitoring well screening intervals should provide sufficient data to evaluate the chemical contamination throughout the water column.

Monitoring well screen slot configuration should be selected based on the filter pack material (backfill) which, in turn, should be selected based on the grain size distribution of the geologic material. This relationship provides the maximum well efficiency when the filter pack is evenly distributed in the annulus.⁶ The use of centering guides to ensure that the screen is centered in the borehole prior to installing the filter pack will ensure that the backfill is evenly distributed.

The use of well screens with filter packs is necessary to prevent the buildup of sedimentation; however, groundwater monitoring wells seldom are designed for maximum efficiency. This may not appear important when a data point is used strictly for sampling and water table elevations, but if well points are used to calculate permeability values, certain care should be exercised. For example, a 10-ft section of 2-in. PVC with a 0.010 in. machine slot opening has an open area of 3.5%.' If well screens are installed into stratigraphic units that have an open area of more than 3.5%, then the well screen will be the limiting factor and the permeability data will be representative of the well screen and not the formation. For this reason, well screens should have open areas equal to or greater than the open area of the aquifer.

A 10-ft section of 2-in. continuous slot PVC with a 0.010 in. slot opening has an open area of 7.6%, which far exceeds that of the machine slot PVC.¹⁰ The stainless steel version with the same dimensions has an open area of 14.0%. Since the maximum open area of a perfect aquifer with rhomboidal packing is approximately 10%,¹¹ the continuous slot well screen offers double the open area and, in most cases, will not be the limiting factor.

An additional problem with in situ permeability tests conducted after the completion of the well stems from well development. Every type of drilling operation changes the hydraulic characteristics in the immediate vicinity of the borehole. Hydraulic conductivity around the borehole tends to be lower than is found in the undisturbed formation. To restore the formation around the borehole to its most representative condition, the monitoring well must be developed.

Typical development techniques include flushing, bailing, mechanical surging, air lift surging and pumping and high velocity jetting. Too often the development technique commonly chosen is dependent on the equipment readily available to the driller. This use of opportune equipment may result in the selection of a less effective development technique. High velocity jetting has been a highly effective development technique and should be specified as the development technique. High velocity jetting will cause volatilization of certain compounds and may reduce concentrations if the monitoring well is sampled shortly after development.

Whether drilling is in unconsolidated or consolidated deposits, the use of drilling muds should be avoided at all costs. Drilling muds reduce hydraulic conductivities and attenuate contaminant concentrations.¹²

A relatively new drilling technique shows great promise for the installation of monitoring wells in formations that require muds to maintain an open borehole. This drilling technique, featured in the August 1985 Water Well Journal, is known as the ODEX method. It employs a retractable air rotary bit that allows the casing to follow the bit, eliminating the need for drilling mud in most cases. As currently utilized by Philip Brien (the driller featured in the article), the casing is rapidly advanced through the overburden until it reaches bedrock. Once solid bedrock is reached, the bit is extracted by rotating the drill stem in the opposite direction. The bentonite can be pumped down through a special injection sleeve while the casing is in place to provide the seal. As the sleeve is removed, the bentonite is allowed to swell. Once swelled, a smaller diameter hammer is advanced through the seal to the desired depth. This method is particularly useful if the objective of the well point is to monitor the groundwater found in the bedrock, because it ensures a high integrity seal.

It is quite possible that this technique could be adapted for the installation of overburden/sedimentary monitoring wells. If this were the case, the use of muds frequently could be eliminated and the drilling fluid could be clean water.

The chemical data base obviously depends on the lateral placement of the monitoring well points and their vertical screened intervals. The drilling fluid and well construction are also extremely important to the groundwater chemistry. If at all possible, the drilling fluid should be clean water. The use of bentonite (sodium or calcium) and cement for seals and grouts likely will have effects on the pH and cation exchange rate.¹¹ The compatibility of these materials (and the monitoring well material itself) with the contaminants of concern should be evaluated prior to use.

The chemical data base is extremely sensitive to sampling procedures, field conditions, equipment and sample handling. Duplicates and blanks (field, trip, equipment) should be a part of all sampling programs to prevent contamination from the sampling procedures. Dedicated equipment can be employed to minimize the potential for cross contamination.

Groundwater sampling often is considered to be simple and routine. However, this component of data collection can have a dramatic effect on the Remedial Investigation (and subsequently site remediation) if it is not performed correctly.¹³

To ensure reproducible data, it is advantageous to conduct

multiple sampling rounds to develop the analytical data base. Since chemical analysis can be extremely expensive, one approach may be to perform partial analysis after the original full comprehensive analysis. Many options exist to provide the analytical data base without exhausting available resources.

CONCLUSIONS

The importance of appropriate field data collection cannot be overemphasized. Collection of unrepresentative field data or reliance upon field data beyond its limitations most likely will lead to unsuccessful site remediation or increased costs due to additional investigation.

With the increasing number of monitoring wells being installed at hazardous waste sites each year, it is extremely important that all investigative programs provide the maximum amount of data. It is especially important for those sites where some type of remedial technology is to be planned and implemented. If these technologies are identified prior to the Remedial Investigation, the collection of field data will be more likely to provide the necessary data base to properly evaluate the applicable remedial options.

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A Practical Methodology for Designing And Conducting Ambient Air Monitoring At Hazardous Waste Facilities

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ABSTRACT

The body of information presented in this paper is directed to those scientists charged with designing and conducting ambient air monitoring for air toxics at hazardous waste or other facilities. The emphasis is on preliminary planning of the monitoring program and the decision paths required to develop a successful program. A decision tree approach is suggested in which the goals of the program are set by asking the basic questions of who, what and for whom. Three basic reasons why toxic air monitoring may be required are: (1) to support an on-site health and safety program; (2) to evaluate ambient levels to which the public may be exposed, and (3) to determine a facility's contribution to ambient air toxic levels.

Development of a project-specific monitoring plan is recommended, and the suggested contents are presented. Instantaneous, continuous and integrated air samples are defined and discussed. A summary of various sampling methods falling under these categories is presented. An overview of QA/QC requirements for both monitoring and analysis procedures also is presented. Finally, several case studies of various air toxic sampling applications are discussed.

INTRODUCTION

Recent ambient air monitoring efforts conducted for a variety of hazardous waste facilities have underscored the lack of specific guidance available for designing and conducting such programs. The majority of existing technical guidance is directed toward specific sampling and analytical procedures. Little attention has been given to the overall monitoring effort, the design or the conduct of the monitoring program as a whole. This situation can be likened to conducting a prevention of significant degradation air monitoring program with guidance only for operating sampling equipment and performing analytical procedures.

Conducting ambient air monitoring for air toxics is becoming more important as regulatory requirements for monitoring increase at hazardous waste facilities. This importance also stems from the increase in adjudicatory proceedings involving liability issues associated with the release of hazardous air contaminants, whether from facilities defined as hazardous waste facilities or from other sources. Regardless of the catalyst, the objective is to determine the existence, magnitude and extent of toxics in the ambient air. The overall trend in monitoring requirements appears to be leading to the protection of the public health and welfare from ambient air toxics in a manner similar to that more traditionally associated with criteria pollutants.

An important implication (for regulatory or adjudicatory purposes) of protecting the public health and welfare from adverse ambient air toxic levels, aside from the problem of defining ambient levels which are adverse, is consistency of approach to the monitoring effort. The authors' intent is to suggest a consistent approach for designing and conducting ambient monitoring programs for evaluating ambient levels of air toxics at hazardous waste facilities or for similar applications. Practical guidance provided is derived primarily from methodologies used to develop and conduct monitoring programs for criteria pollutants and recent experience in conducting a variety of ambient air toxics sampling programs. Several case studies upon which this paper was based are discussed, including a retrospective review of the advantages and disadvantages of the monitoring programs. A discussion on the relative usefulness of the data obtained is included, as well as a discussion of the problems encountered and steps taken to resolve them.

DECISION TREE APPROACH

A decision tree approach has been suggested to facilitate designing and conducting ambient air monitoring programs for toxics at hazardous waste and other facilities. The approach is depicted in a simplified decision tree presented in Fig. 1. An essential part of the approach is identification of program objectives. The reason for the monitoring program is the most important question that should be asked: "Why is the program being conducted?" Once the program objectives have been established, the Program Planning can begin. By answering additional questions (Fig. 1), one can design the program. Additional quetions must be considered for program implementation. As the decision process continues, the more subtle issues are identified, thus completing the process and filling out the decision tree and defining the scope and content of the air monitoring program.

OBJECTIVES

The initial aspect of the decision process (Fig. 1) is the determination of WHY the monitoring will be conducted. Although this question is basic to all monitoring programs, it is perhaps more essential to ambient air toxics programs, as the answer sets the course of the entire program. The answer to why a program is being conducted can be classified into one or more of the following three major categories:

- To determine a facility's contribution to ambient contaminant levels and regulatory compliance
- To support on-site health and safety efforts
- To investigate ambient levels to which the public may be exposed
 - Each of these major reasons for a monitoring program is dis-

cussed below.



Figure 1 Air Monitoring Program Decision Tree

Contribution to Ambient Contaminant Levels

To adequately determine the contribution from a given facility to ambient contaminant levels requires an upwind, downwind monitoring network. This is particularly true if the facility in question is located in an area with other facilities contributing to ambient contaminant levels. Under this scenario, the concern is not to determine instantaneous or acute contaminant levels or even to determine chronic levels, but rather to determine longterm (1 to 24 hr) ambient concentrations as accurately as possible. Attention must be paid to fluctuations in wind direction, as source/receptor alignment is critical to obtaining meaningful results from the monitoring. Additionally, a high degree of sensitivity in both the sampling and analysis procedures may be necessary to distinguish between very small changes in contaminant levels from one sample location to another.

Health and Safety

The primary focus of on-site health and safety programs is to protect personnel from the acute and/or chronic effects of exposure to toxics. With respect to air quality, protecting against acute or chronic effects requires separate and distinct monitoring approaches. Each approach utilizes unique and specialized sampling equipment with associated operational and analysis requirements. Therefore, one must determine which type of exposure protection is necessary to develop a suitable monitoring program.

Acute

Protecting against potentially acute effects of exposure to air toxics implies the need to determine real time contaminant levels on a continuous basis. Typically, the equipment used for this purpose would be portable, providing a continuous readout of contaminant concentrations as referenced to some standard. Exceeding a predetermined action level would then trigger implementation of a contingency plan. The shortfall of these types of monitoring devices is their inability to accurately qualify and quantify the (all) types of contaminants present. However, they do satisfy the primary goal by providing a real time indication of ambient air toxic levels without the need for time-consuming and expensive sample collection and analysis.

Chronic

Protecting against potentially chronic effects of exposure to ambient hazardous air contaminant levels implies the need to identify and quantify the types(s) of contaminants present. Equipment used for this purpose is portable and can be used stationary or on personnel. This equipment samples a known quantity (volume) of air for a specified sampling time (typically 1 to 24 hr). Although this type of sampling does not readily allow for field analysis, a very accurate determination of the type(s) and concentrations of air contaminants can be made. This type of analysis is crucial in determining potentially chronic effects of air toxics, as the effects will vary by contaminant, by concentration and by length of worker exposure.

Public Exposure

Evaluation of ambient hazardous air contaminant levels to which the public may be exposed usually requires a determination of fence line contaminant levels. This requires sampling at more than one location to account for changes in wind direction that may occur during the sampling period. It is assumed that fence line concentrations represent the maximum level to which the public may be exposed. Since concentrations will decrease with transport from the property. Under some situations, it also may be necessary to monitor ambient hazardous air contaminant levels at nearby residences. In the majority of evaluations of contaminant levels to which the public may be exposed, the concern will be to identify and quantify contaminants with the potential to cause chronic effects.

PLANNING

Answering the planning questions posed on the decision tree (Fig. 1) will clearly define the methods required to achieve the identified program objectives. Development of a project-specific monitoring plan encompassing all the issues raised in the decision process is essential. Regardless of which branch the decision process follows, a monitoring plan of one form or another should be developed. Prior to developing the monitoring plan, all the issues outlined on the decision tree should be addressed, with project-specific issues included in the monitoring plan. Suggested contents of a monitoring plan are presented in Table 1.

Air Sampling Methodologies

An integral part of the monitoring plan is to determine and develop the sampling methodologies to achieve the goals of the monitoring program. Sampling for specific hazardous compounds, especially organics, in the ambient air can be extremely complex. This complexity is due to the high degree of variability associated with measurement of air contaminant concentrations including source variability, meteorological variability, spatial variability, personnel activity variability and influence of extraneous sources variability (on-site or off-site). Adding to the complexity of the monitoring task are the wide variety of contaminants of interest and the lack of standardized sampling and analysis procedures.

An initial step toward establishing some standardization of sampling and analysis procedures is presented in a compendium of specific guidance in Table 1-Suggested Contents of Air Toxics Monitoring Plan determination of selected toxic organic compounds in ambient air.' At present, the compendium is limited to guidance on five methods utilizing different collection media. The various methods and types of equipment available for conducting air sampling analyses are related to the kinds of contaminants of concern, the range of contaminant concentrations expected and the sampling period and sampling duration. Some sampling methods are specific to a single contaminant, while others will respond to many different contaminants and provide total gross indications of the possible presence of many contaminants. Some methods allow determination of a contaminant in different ranges and have different sensitivities (minimum detectable limits) to various contaminants. Some methods provide sampling results over different time periods due to in-

1.0	INTRODUCTION	

- Purpose
- Scope Objectives
- 2.0 SITE DESCRIPTION
 - Topographic Description Land Use Description

 - Source Description Climatological Description
- 3.0 HONITORING PROGRAM DESCRIPTION
 - Nonitoring Locations (relationship to sources, property boundaries, structures, etc.

 - structures, etc. Photographs Instrumentation (air quality and mateorology) Collection Hedia (type, preparation, quantity) Monitoring Schedule (averaging, period, frequency, duration) Operating Procedures (flow rates, volumes) Maintenance Procedures Sample Handling Procedures (installation, shipment) Laboratory Procedures (sample preparation, methods, sensitivity)
- 4.0 DATA PROCESSING AND REPORTING

 - Format Frequency Content

5.0 QUALITY ASSURANCE (field, laboratory, reporting)

- Calibration Frequency Independent Audit Program Internal Quality Control Procedures Data Pracision and Accuracy Calculation Procedures Blank (field, laboratory) Duplicates Breatthrough Solas

- Spikes Chain-of-Custody
- 6.0 REFERENCES

herent properties of the method and equipment involved. A summary of air sampling methods is presented in Table 2.

The different types of air samples obtained can be classified according to sampling duration. The three classifications are:

- Instantaneous samples
- Continuous samples
- Integrated samples

Instantaneous samples are those which are collected instantaneously over an extremely short period of time in the range of a few minutes or less. Continual sampling can be accomplished by continually taking instantaneous samples. These often are referred to as grab samples. Continuous monitoring includes methods which provide a continuous readout of instantaneous changes in concentration. This method usually utilizes a continuous instrument with a constant meter readout and sometimes is used with a chart recorder to provide a continuous record of contaminant concentration levels with time. Integrated samples are those collected over a time period usually in the order of an hour or more, extending to a day or, in some cases, a number of days. The result of integrated sampling provides a given value which is essentially an average value for the sampling period of concern.

Sampling methods can be classified further by the physical and chemical properties of the contaminants of concern. Physical properties that must be considered include: boiling point, vapor pressure and solubility. Compounds with low volatility (boiling points greater than 200 °C) may exist as particulate matter, while compounds with higher volatility usually will be in the gas phase. Sampling techniques can vary greatly depending on whether compounds exist in the gas phase, solid phase or are particulate-bound.2

	Sema le	Results	Results	Detection Lisit	Compounds	
fit Lines	Callection	Type	Trat.	(999)	Petected	Company 1
Celorimtric Betector Tubes	Instantaneous	Historic	Øfract Beading	0.1-1.0	Varieus Organics and Inorganics	inexpansive, mend inventory of different tubes, cross sensitivities
Flam Ionization Betector (FID)	Cont I nuovis	Real Time	Birect Reading	0.5	Rost Organics (Total)	Higher cest, good for screening
Photosianization Detactor (PID)	Instantaneous Integrated	Real Flag	Birect Reading	0.1	Most Organics Some inorganics Normethane (Total)	Nigher cost, good for screening
f 1e1d GC (f 19/P10)	Instantaneous Integrated	Historic, Short Time Delay	Øiract Reading	0.001-0.i	Most Organics	Higher cost, Mire training, Most run standards
Advarbant Radia/ Filtration	integrated	Historic	Lab Analysis Regulred	Variable	Total or spacios	Some Lob analyses can be costly and take the for results
Air Collection Bogs, Rigid Containers	instantanoous Integrated	Historic	Lab Anglysis	Varlable	Total or species	Peestikle prob- leass of inter- actions eigh contaminants and contaminants
Infrarad Ang Typer	Cant Invars	Apal Time	Birect Booting	1-10	Nost Organics Sam Inorganics	Bigher cast, irigh volume of sample

Particulate Sampling

Filtration is a sample collection technique most commonly used for sampling particulate matter and other particulate-bound components. Various filter media are available, and some are beter suited to collection of certain compounds. Filtration media include:

- Cellulose
- Glass or quartz fiber
- Membranes
- Teflon coated glass fiber

Particulate sizing may be of interest in some situation, and there are techniques available for this. However, particle sizing can increase the complexity of sampling.

Examples of particulates or particle-bound components include: fugitive dusts, trade metals, PCBs and coal tar volatiles. Methods for sampling PCBs utilize polyurethane foam (PUF) with both low volume and high volume sampling systems.³

Gas Sampling

A number of different techniques are available for sampling gas phase compounds. Selection is important because some techniques are better suited to sampling certain compounds and not others. Available techniques include:

- Colorimetric detector tubes
- Solid/liquid adsorbents
- Grab sampling (bags, rigid containers)
- Flame ionization detectors (FID)
- Photoionization detectors (PID)
- Infrared analysis

Meteorological Monitoring

The importance of acquiring meteorological data concurrently with ambient air data can vary significantly. However, in almost every air monitoring situation, the acquisition of some form of meteorological data is required. The parameters required from one monitoring program to another may vary, but in almost every situation, some determination of wind direction and wind speed is essential. Depending on the overall goals and duration of the monitoring program, the meteorological monitoring equipment

may vary from a wind sock to a fixed 10-m instrumented tower with strip chart or cassette recording devices.

Quality Assurance

The overall objective of quality assurance/quality control (QA/QC) is to increase the level of confidence of the sampling or measurement data of air contaminant concentrations. Quality control can be considered normal procedures and activities (routine checks, calibrations, dúplicate samples, split samples, blanks and spiked samples) that increase quality of results. Quality assurance consists of activities that provide assurance that the quality control functions are performed adequately. In air toxic sampling, the terms QA/QC commonly are used collectively to indicate a variety of procedures and activities utilized to meet the overall objective of improving data quality.⁴ QA/QC elements of an air toxic sampling program commonly include:

- Calibrations (routine and audit)
- Document control
- Data validation
- Prevention maintenance (equipment)
- Training
- Inter- and intra-laboratory testing
- Cross-methodology correlation/verification

Some of these elements should be part of all air sampling programs, while others may be included in larger sampling efforts. QA/QC activities pertain to field sampling efforts as well as laboratory analysis. Laboratory analysis QA/QC activities usually are easier to implement than those for field activities; it is often simpler to control variables in the laboratory, as most laboratories have formal QA/QC plans and participate in inter-/intralaboratory testing programs. QA/QC activities for field sampling efforts include:

- Calibration (zero/span checks)
- Sample duplicates/split samples
- Sample blanks
- Spiked samples
- Standard reference materials
- Co-located samplers
- Cross-method correlations
- Documentation

Calibration of field sampling systems is an integral part of QA/QC activities and should be performed. Calibrations should include flow rates, volume, pressure, temperature and other meteorological factors. For continuous meters, calibrations should include precision and accuracy checks with zero and span gas responses and use of standard reference materials, certified gases or standard traceable calibration gases. Since field efforts tend to be expensive, consideration should be given to collecting duplicate samples during the initial field effort because additional sample collection cost is usually minimal compared to the program as a whole. Decisions regarding analysis of duplicates can be made after the field effort, since laboratory costs increase proportionally with the number of samples analyzed. If possible, it is often more advantageous to corroborate results by using multiple methodologies (i.e., detector tubes, absorption tubes, bags, etc.)

Flow rates and volume measurements should be calibrated using primary standards (i.e., bubble flow meters or wet test meters) and/or checked with transfer standards (i.e., calibrated rotometers or mass flow meters).

Documentation is an important aspect of QA/QC since it allows verification of QA/QC activities that have been performed and also provides an indication of the overall quality of the results of a sampling program. The advantages of having a paper trail documenting activities cannot be overemphasized, especially for ambient hazardous air monitoring programs where data may be required by regulatory authorities used for litigation, remediation design or assessment of public risk. Examples of documentation include field logs, data sheets, calibration records and chain of custody forms.

A major benefit of utilizing QA/QC programs is that problems may be detected in the early phases of the sampling program, thus allowing implementation of corrective actions or program modifications with minimal loss of data or time.

IMPLEMENTATION

One of the major questions regarding program implementation (Fig. 1) is who is to conduct the monitoring. Expertise is required in program design and field implementation. Is the specialized expertise required available in house? Laboratories that have GC equipment do not always possess the capabilities to satisfactorily handle air samples. Care should be taken when selecting air analysis laboratories. A frequent concern with regard to air analyses is the turnaround time. Due to recent demand, delays in receiving analysis results can be quite common.

Another major consideration is program cost. Costing may be considered a planning function. However, the program should be planned first, costed and then reevaluated as needed to assess the program with regard to costs versus benefits. The benefits usually are associated with the level of confidence in the results or the degree of uncertainty with regard to concentrations of air toxics. Major costs can be assessed as labor, equipment and laboratory charges. Cost for continuous equipment can require high cost initially. However, major costs of air toxics monitoring are usually associated with laboratory charges.

CASE STUDIES

Several case studies are presented below which show the wide variety of applications for monitoring of hazardous air contaminants at hazardous waste and other facilities.

Hazardous Waste Landfill Site

The site in question is an inactive 24-acre site which was used to landfill industrial process wastes generated from the mid-1960s to 1977. Process wastes included salts and cell bath (barium, calcium and sodium chlorides), contaminated discarded cell rubble, a variety of chlorocarbons and other organic and inorganic wastes.

The site was closed in 1977, and a clay cap was completed in 1978. A groundwater recovery system was installed to remove and treat contaminated groundwater and reduce off-site transport of contaminants with groundwater. As part of an endangerment study, a review (including modeling) of the air pathway raised some concern regarding airborne contaminants due to potential for volatization of chemicals and subsequent off-site transport. An ambient air sampling program including sampling for selected contaminants and meteorological parameters was initiated at the site to provide more information regarding airborne concentrations of site contaminants.

Due to the different natures of the contaminants of concern, three different sorbent media were used. These included Tenax for volatile nonpolar organics, Carbon Molecular Sieve (CMS) for highly volatile organics (i.e., vinyl chloride) and inorganics, and XAD for compounds such as hexachlorobutadiene.

The objective of the sampling was to establish the potential for air contaminants coming from the site. A major concern was the potential for interferences from other waste sites and/or industrial sources in the area. Five sampling locations were used to collect concurrent upwind and downwind samples required to isolate and identify emissions from the site and any potential off-site upwind sources. The sampling period was three days during different times of the year to obtain data on seasonal variability.

Some insights associated with this air sampling program involved the sensitivity and selectivity of the methods. In many cases, as in this one, the concern is associated with long-term low level releases and not necessarily acute short-term releases. Therefore, it is necessary to push to the limits of both analytical and sample collection sensitivities in order to be able to make meaningful conclusions. The results obtained have been extremely low and mostly below detectable limits. Indication of upwind off-site sources of some contaminants of interest was found.

Firefighter Exposure Study

This study consisted of designing and implementing an air monitoring program to monitor firefighter exposure to toxic materials encountered during firefighting operations. The air monitoring program is part of an overall health hazards study of firefighters in a large municipality. The study also included a medical surveillance program with an objective of correlating air monitoring and medical testing results. A varying number of chemical compounds can be produced and released during fires. Many variables control the types of compounds that become byproducts of combustion with the most important variables being the type of material which is burning, the temperature at which it burns and oxygen concentration present. The combustion of material containing nitrogen, sulfur and halogens in the presence of carbon and hydrogen can form hydrogen cyanide, nitrogen oxides, sulfur dioxide, ammonia and halogen acids. Other toxic chemicals of concern are halogens, aldehydes and vinvl chloride.

The study focused on two firehouses with the reported highest number of fire incidents in the City of Buffalo. These fire houses are comprised of approximately 100 firefighters. Over 50 of the 100 firefighters actually participated in the air monitoring program.

The air monitoring program required the use and assembling of specialized sampling equipment that would sample the air for various toxic compounds, be worn by firefighters without hampering them during performance of their normal duties and also stand up to the hostile environments to which firefighters commonly are exposed. The equipment included sampling pumps, colorimetric detector tubes, sample manifolds, adsorbent tubes, particulate filters, temperature monitors and a carrier pack.

Personal samples were collected in the breathing zones of the firefighters during their responses to incidents. If respiratory protective equipment was being worn, samples were collected outside the face pieces. The samples collected represent the potential inhalation exposure of firefighters not wearing respiratory protection. Samples were collected during various stages of firefighter activities (i.e., rescue, fire control, overhaul).

The air monitoring was performed over a 10-day period in January of 1986. During this period, the two firehouses involved in the study responded to 106 calls, 14 of which were of sufficient duration and magnitude to monitor. The characteristics of these fires (i.e., type, activities, smoke intensity, etc.) and air sampling information were recorded.

Sampling insights drawn from this study relate to sampling periods, sample duration and equipment. Although the occurrance of fires can be thought of as random, future sampling efforts should be focused on periods of expected higher frequencies of events. Sampling duration is of concern because of the great variability associated with different fires as well as the different activities of each firefighter. Recommended modifications to equipment are associated with cold weather (i.e., tubing) and also loss of samples from water.

Shopping Center Study

Reports wered received of chemical odors from a number of small stores in a shopping center complex. The complaints consisted of chemical odors causing varied symptomatic health related complaints of headaches, nausea, eye and nasal irritation, etc. Inspections of the most obvious potential causes were performed by respective contractors (i.e., heating and air conditioning systems, gas services, fire department). No malfunctions or leaks were found that could explain the odor. Air sampling was performed to identify the type and level of air contamination present and to locate the source. It was necessary to determine the extent, if any, of health hazard posed by the contamination and to locate the source of the odors so that mitigation measures could be implemented. Immediate response was required.

Four major air quality sampling techniques were used due to the unknown nature of the type, levels and source of contamination. The methods used were total volatiles screening, colorimetric detector tube sampling, adsorbent tube sampling and bag sampling. Screening for total volatiles was performed with two photoionization analyzers; a Model P1 101 by HNU System, Inc. and a TIP by Photovac, Inc. Screening of indicated concentrations was performed in the stores and locations where the problems were reported. The analyzers were used continuously throughout the area to assess variations in ambient concentrations.

Colorimetric detector tube sampling indicated the presence of benzene and potentially other aromatic compounds such as toluene and xylene, compounds indicative of those found in gasoline.

Adsorbent tube samples were collected and sent to a laboratory for analysis. The results confirmed and expanded upon the detector tube results. Bag samples collected were sent to a different laboratory whose results supported those of the previous techniques.

A potential source of the gasoline was traced to a storage tank and filling facility located at an ambulance service on an adjacent property. It was suspected that gasoline collecting under the building could be the result of a leak in the tank, associated piping and/or spills due to overfilling. Reports of a recent spill/incident due to overfilling and the fact that the complaints were recent and not of a chronic nature indicated that spills due to overfilling most likely were responsible for the problem.

As a result of this project, we concluded there was a need to utilize as many techniques as possible to increase the degree of information and level of confidence of the results obtained. Another important factor is the availability of qualified analytical laboratory service. The current turnaround from most laboratories can create a major problem for a project such as this, where results are needed rapidly. Even premium rates for priority service do not guarantee quick service. For projects with the potential for litigation, it is advantageous to corroborate results with different methodologies and different laboratories.

CONCLUSIONS

Monitoring for air toxics in the ambient air at hazardous waste and other facilities is becoming more important and increasingly necessary. Because the results of monitoring programs are being used to demonstrate regulatory compliance and to resolve matters of litigation, they must be obtained in a rigorous and defensible manner. Since no standardized methodology exists for developing and conducting ambient air toxics monitoring programs, an approach has been presented in this paper.

The approach presented uses a decision tree to first identify

program objectives and then to develop planning and implementation methods to achieve them. Defining the goals of the program is seen as the most important part of the decision process. Three primary goals are identified: (1) to support on-site health and safety efforts, (2) to investigate ambient levels to which the public may be exposed and (3) to determine a facility's contribution to ambient contaminant levels and regulatory compliance.

An integral part of the approach is the preparation of a site specific monitoring plan encompassing the issues raised in the decision process. Suggested contents of an air monitoring plan include site description, monitoring methods (for both air toxics and meteorology) and QA/QC procedures. Regardless of the size of the monitoring efforts, a monitoring plan of one form or another should be prepared.

Several air sampling methodologies are suggested for sampling particulate and gas phase air toxics. These methodologies have been placed into three classifications based on sampling duration: (1) instantaneous samples, (2) continuous samples and (3) integrated samples. Depending on the application, any or all of these sampling classifications may be employed.

It is generally felt that some meteorological monitoring should be conducted concurrently with almost every air toxics monitoring program, especially for wind direction and speed. The importance of the meteorological monitoring will vary depending on the goals of the air monitoring program.

The importance of QA/QC procedures for both field and analytical portions of the monitoring program cannot be overstated.

Use of rigid QA/QC procedures is the only way to assure defensible air toxics data for regulatory compliance or litigation purposes.

The methodology suggested for designing and conducting ambient monitoring at hazardous waste facilities can simplify the process for obtaining air toxics data. However, the problems and decisions faced are not simple ones. As evidenced in the case studies, a variety of applications exists for air toxic monitoring. Although the decision process is essentially the same (decision tree) from application to application, the nuances within each application require the analyst to draw on past experience to develop a program to meet the unique needs of each new project.

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Low Level Groundwater Comtaination Investigation At the Cleve Reber Superfund Site

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ABSTRACT

A groundwater investigation was performed at the Cleve Reber Superfund Site to estimate the extent of hexachloro compound migration from the site at the ng/l (ppt) levels. This study of low level groundwater contamination was performed due to the several orders of magnitude difference between the normally used laboratory detection limits and the very low health risk criteria for the compounds of concern. Following the establishment of quality assurance procedures for laboratory analyses, drilling and well installation and sampling, a series of "ultraclean" monitoring wells was installed around the site and sampled.

The results of the study indicated that the site contributes very little, if any, contamination to the groundwater. Additionally, the investigation concluded that water samples obtained from wells installed and sampled using standard techniques have falsely high contaminant concentrations.

INTRODUCTION

The Contract Laboratory Program (CLP), which performs chemical analysis of environmental samples for the Superfund program, reports contract detection limits that are several orders of magnitude greater than the 10^{-6} lifetime excess cancer risk concentrations for numerous compounds on the Hazardous Substance List (HSL). The 10^{-6} lifetime excess cancer risk is the target criterion generally used by the U.S. EPA to evaluate public health risks resulting from a hazardous waste site. This variation between the 10^{-6} lifetime cancer risk concentration (criterion concentration) and the detection limits reported by laboratories can lead to difficulties in assessing site risks. When a compound is not found, the assumption that the compound is not present can lead to underestimation of site risks. Conversely, the conservative approach of assuming the compound is present at the detection limit may significantly overstate the site related risks.

The Cleve Reber Superfund Site Remedial Investigation and Feasibility Study (R1/FS) was completed using standard CLP detection limits for the compounds of concern. These detection limits were up to three orders of magnitude greater than the criterion concentration for the major site contaminant of concern, hexachlorobenzene (HCB). After the final R1/FS was issued, the U.S. EPA requested a one-time sampling of selected existing monitoring wells surrounding the site. The samples were analyzed for HCB using detection limits at or below the criterion concentration (21 ng/l or ppt). The results of this sampling indicated that the contaminant of concern was present in a thin, water bearing zone located approximately 40 ft below the ground surface. Positive results were reported one to two orders of magnitude above the criterion concentration. This original low concentration sampling effort was conducted without the benefit of a detailed quality assurance plan due to severe schedule restrictions. The U.S. EPA then requested an extensive investigation of this shallow sand zone to map a contaminant plume at ppt levels. This new investigation, funded by the U.S. EPA, was to include a quality assurance plan that considered the sensitivity of a ppt investigation. The one-time low concentration sampling was important since it identified a potential health risk previously unidentified. Although the sampling was conducted without extensive quality assurance procedures, confidence in the data existed because of good duplicate sample results, and because residential well samples were clean, as expected.

SITE BACKGROUND

The Cleve Reber site is located in an undeveloped area between Baton Rouge and New Orleans, Louisiana, about 2 mi east of the Mississippi River. There are approximately 25 homes within 0.5 mi of the site, with the nearest town (Sorrento, population 1,000) being about 2 mi to the northeast. The area surrounding the site has mixed uses. There is some agriculture within 0.5 mi of the site, but most of the immediate surrounding area is undeveloped and swampy land. There is a combination municipal/industrial landfill approximately 0.5 mi south of the site, and there is extensive industrial development nearer the Mississippi River and along its banks.

Before waste was disposed there, the site was used as a source of borrow soil for the construction of nearby highway projects. The resulting borrow pit was later used for municipal and industrial wastes disposal. The pit area was about 600 ft by 1,400 ft. Test borings drilled within the pit indicate that wastes were buried at depths of about 6 to 20 ft. Disposal operations were halted in 1974 prior to completely filling the pit. Consequently, a large pond formed at the northern end of the site (Figure 1).

The site not only held state permits for the disposal of municipal wastes, but also accepted industrial wastes. Reportedly, about 95% of the waste disposed was municipal refuse. Records show that industrial wastes were disposed on-site in drums and as bulk sludges in segregated areas of the fill. The largest reported volume of industrial wastes disposed on-site was "hex pot" bottoms containing hexachlorobenzene (HCB), hexachlorobutadiene (HCBD) and hexachloroethane (HCE). These chlorinated compounds are the site contaminants of primary concern due to their carcinogenic nature. Although segregation of the wastes may have been attempted during disposal activities, testing performed on leachate samples detected the presence of hazardous substances throughout the waste pit, making the entire volume a hazardous material.



Figure 1 Cleve Reber Superfund Site Plan

Preliminary evaluations suggested that public health and environmental hazards posed by the site were related primarily to surface contacts and to groundwater. The remedial investigation (RI) concluded that direct contact with contaminants on-site clearly posed an unacceptable hazard. Contact with contaminants that may have migrated off-site by surface water runoff was also a concern identified in the RI. Remediation of the surface contact related contamination was called for in the RI/FS, including isolation of the contaminants and prevention of migration by capping the site and diverting surface water runoff. The presence of groundwater contamination and the need for groundwater remediation were not verified by the RI.

BACKGROUND GROUNDWATER DATA

The major fresh drinking water aquifers in the vicinity of the site are the Norco and Gonzales Aquifers. The Norco Aquifer is the major source of drinking water for residents near the site, while the Gonzales Aquifer is a major regional source of water for both private and industrial uses. The Norco Aquifer is located at a depth of about 250 ft below ground surface at the site. The top of the Gonzales Aquifer is reportedly about 500 ft below ground surface. A generalized geologic section of the area is presented in Figure 2. The soils overlying the Norco and separating the Norco from the Gonzales were reported to be low permeability, fine-grained soils (clays and silts). Water levels in both aquifers are artesian and are under free-flowing conditions for much of the year. Water levels in these aquifers reportedly rise and fall with the Mississippi River stage.

The RI concluded that the Norco and Gonzales Aquifers are not likely to be contaminated by the site now or in the future. The upward hydraulic gradient from these aquifers due to the artesian conditions would cause contaminated groundwater to move upward and away from these aquifers. The thick layers of low permeability soils also provide a barrier to downward groundwater flow. The density difference between the hexachloro compounds, and in particular HCB and water, were considered but were not considered great enough to overcome the hydraulic and physical barriers to downward flow.

The RI also identified a sand zone at a depth of 40 ft below the ground surface as shown on Figure 2. The sand zone is approximately 5 to 10 ft thick in the vicinity of the site. There are no documented current uses of this groundwater source in the area, although an onsite well is screened in this zone. This well reportedly was used to produce water for use on-site. This zone could be used as a source of small volumes of water, such as for domestic use. The RI also indicated that the soils separating the 40-ft sand zone

and the waste pit were more permeable than previous investigations had indicated. These soils are primarily fine-grained clays and silts with laboratory permeabilities in the range of 10^{-7} to 10^{-9} cm/sec. However, in-place test results were in the range of 10^{-3} to 10^{-5} cm/sec. It appears that secondary permeability features such as root holes, fractures, slickensides and sand lenses, identified by visually examining the soil samples, control overall soil mass permeability. Laboratory tests do not accurately account for the influence of these secondary features. Therefore, it was concluded that some contamination could be expected to reach the 40-ft sand zone.

DEPTH (FT.)



Figure 2 Generalized Geologic Section at the Cleve Rebel Site

Although the geologic and hydrogeologic findings suggested the possibility of contaminant migration in shallow soil zones, samples from wells screened in those zones gave negative results when submitted for standard CLP analyses. However, as Table 1 shows, the detection limits for those standard analyses are up to orders of magnitude higher than the health criterion concentration for site contaminants. Therefore, the U.S. EPA requested a limited sampling and testing program for the shallow monitoring wells installed during the RI using specially developed analyses to provide detection at the criterion concentration of HCB (which is 21, ng/l).

In response to the U.S. EPA's request, five perimeter wells that were used previously only as piezometers and were screened in the 40-ft sand zone were sampled. These samples were tested using standard CLP detection limits for the complete HSL, and for hexachlorobenzene using a detection limit of about 5 ng/l. Due to schedule constraints, only HCB was analyzed at low detection levels and no time was available to develop a quality assurance plan for this sensitive work. Water samples from all of the wells showed the presence of hexachlorobenzene at concentrations ranging from about 0.2 to 7.4 μ g/l (ppb). There was confidence in the low level analytical procedures since split samples had similar results, and residential well samples obtained were analyzed as being clean, as anticipated. After receiving these results, the U.S. EPA requested the development of a plan to determine the extent of groundwater contamination in the 40-ft sand zone, with detection capability at or below the criterion concentrations listed on Table 1.

Table 1 Comparison of CLP Contract Detection Limits And Criterion Concentrations

Carpound	CLP Detection Limits (mpb)	Criterion <u>Concentration (pob)</u>
Hexach1 crobensene	20	0.021
Henachlorobutadiene	20	0.450
Hexachloroethane	20	2.400
	• · · · ·	

*Criterion in this case is 10^{-6} excess lifetime cancer risk in use of a drinking water supply with the listed contaminent concentration.

INVESTIGATION PLANNING

Objectives

The major objective of the study was to verify the presence of hexachloro waste contaminants in shallow groundwater in the site vicinity. Results of previous analyses from samplings of standard PVC monitoring wells were positive at concentrations above the health risk criteria contamination. The zone in which these positive results were detected was the thin sandy layer approximately 40 ft below the ground surface. The investigation focused on that layer. Another objective of the study was to help the U.S. EPA evaluate whether similar low-level groundwater contamination studies might be feasible for other sites. Technical feasibility and cost were to be evaluated at the completion of the investigation. Documentation was therefore extensive.

Well Locations

Existing data for the site suggested that little gradient existed in the shallow groundwater near the site, except for a general gradient away from the site due to leachate mounding within the waste pit itself. Consequently, there was no reason to concentrate the monitoring in any direction from the site. Wells were planned in equidistant locations (concentric rings) from the site center. Each ring was planned to comprise six wells, equally spaced in plain view on the ring.

One of the contamination avoidance measures was to drill and sample wells in an order of least-contaminated to mostcontaminated. The first ring of wells was to be about 0.5 mi from the center of the site, since at this distance the groundwater was expected to be clean. The next ring was expected to be moved inward, to perhaps 0.25 mi of the site center, unless positive analytical results were received from samples from the first ring of wells. Decisions on the location of the additional well ring(s) proceeded quickly to avoid downtime in the field. This meant that the laboratory had to provide results within 48 hr of their receipt of the samples.

In addition to the monitoring wells located on the rings surrounding the site, the study also included the installation of wells adjacent to existing monitoring wells screened in the 40-ft sand layer. The existing wells that were sampled subsequent to the R1 were constructed of PVC pipe using only standard decontamination and drilling procedures. Since special techniques were planned to prepare the wells for sampling and analysis for low levels of contamination data, it was proposed that two "ultra-clean" wells (described in Well Installation Techniques section) be installed adjacent to two previously installed PVC wells. These wells would be simultaneously sampled and the analytical results compared to estimate the effects of drilling, development techniques and well materials on low-level analytical results.

WELL INSTALLATION TECHNIQUE

Drilling was performed using dry augers, rather than the wash technique typical in south Louisiana. The auger technique introduces no external fluid into the borehole, and was expected to provide a leaner hole. An oversized surface hole was bored with separate equipment to avoid introducing surface soil contamination into the well hole. This initial hole then was cased off as a safeguard.

Although the auger drilling specification was a simple one, it

was difficult to fulfill, since drillers in south Louisiana prefer to use wash techniques. The heavy clays which predominate in the region are very stiff and plastic and place great torque demands on the drilling rigs using auger methods.

Procedures used for decontamination downhole drilling tools and equipment included the following:

- · Scrubbing with potable water to remove accumulated mud
- Rinsing with kerosene
- Rinsing with hexane
- · Scrubbing with trisodium phosphate
- · Cleaning with high pressure steam

Stainless steel well casing was used for well construction since the contaminants of concern might be expected to be in PVC. The rigorous steam cleaning specificiations led to concerns that Teflon casings would deform and Teflon's higher cost was not warranted since no inorganic contaminants were of concern.

Glass beads were used as the gravel pack medium to avoid artifact contamination. This was a field change, since rinse samples of the same used for the first few wells in this study proved to be contaminated with HCB at unacceptably high levels.

Rigorous decontamination procedures were followed for well materials also. Also casing and screens were washed first with acetone to remove paint and markings. They were then steam cleaned.

Once tools, equipment, well casing and screen were decontaminated, they were wrapped in clean polyethylene sheeting until they were used. Equipment which fell to the ground or which became soiled in any way was decontaminated again before use. Drill crew members changed coveralls and gloves between drilling the borehole and installing well materials.

A series of rinse samples was collected periodically for analysis, to evaluate decontamination effectiveness. These rinse samples were collected from augers, drill rods, well casings, screens, surface casing and gravel pack material (first sand; later glass beads). The decontamination water also was sampled and analyzed.

Well Development and Sampling Methods

Once the wells were installed, special well development and sampling techniques were needed to avoid introducing external contamination. The only pieces of equipment to contact the well water were decontaminated stainless steel bailers with teflon check valves and a short length of hose for the development pump. The bailers and check valves were decontaminated in a laboratory by solvent and distilled water washing and baking in an oven at a temperature of 392 °F for 1 hr. The decontaminated equipment was wrapped in aluminum foil until use.

Development of the wells was by surface mounted centrifugal pump, with the intake hose connected to a bailer lowered to the bottom of the well. A high volume of water was flushed from each well at high flow and high turbulence. The purpose of this turbulence was to encourage sediments to flush completely out of the well. Since HCB and the other contaminants of concern have high octanol-water partition coefficients, they have an affinity for sediment over water. For this reason, removal of sediment was especially critical. The high development flow also was expected to flush any residual external contamination from the well casing and allow a representative sample of groundwater to be obtained.

To sample each well, a bailer was attached to a decontaminated stainless steel cable and the bailer was raised and lowered using a downrigger reel (heavy-duty fishing reel). The reel was mounted on a stepladder over the top of the well. During the bailing process, the bailer touched nothing except the cable, well water and the inside of the casing. The bailer was not allowed to be completely submerged, so the cable would not become wet.

Only one member of the sampling team (with clean gloves) was allowed to handle the bailer itself. If the gloves touched anything other than the bailer, new gloves were put on before proceeding.

In order to estimate the effectiveness of the bailer and other equipment decontamination procedures, a series of rinsate samples was planned. This included rinsate samples from bailers, stainless steel cables, the downriggers and decontamination fluid containers.

Laboratory Methods

West Coast Analytical Services (WCAS), the laboratory selected to perform the analytical work, performed the testing at reduced detection limits and provided results within 48 hr after receiving the samples. The fast turnaround was needed to properly locate additional monitoring wells (i.e., further or closer to the site).

U.S. EPA Method 612 for Gas Chromatographic Analysis of Chlorinated Hydrocarbons was modified to reach the required detection limits. The Method Detection Limit (MDL) of Method 612 for hexachlorobenzene is 50 ng/l, although CLP and standard laboratory analyses typically report detection limits of 20,000 ng/l (20 ng/l). WCAS had to reduce its MDL one order of magnitude (10 times) to achieve a MDL of 5 ng/l for HCB and similar compounds. Modification in Method 612 to achieve this reduction included doubling sample size from 1 to 21 and concentrating the sample to 2 ml rather than the usual 10 ml.

Validation of the above revised analytical method included:

- Analysis of six distilled water replicates (same source) spiked at 20 ng/l to estimate relative standard deviation (RSD), percent recovery and MDL
- Analysis of six replicate field samples with low levels of contaminants to estimate RSD and MDL
- Analysis of six replicate field samples spiked with twice the background levels to estimate percent recovery and RSD

In addition to the quality assurance procedures required by Method 612, two additional procedures were followed. The laboratory performed a daily mid-range calibration at an HCB concentration of less than 100 ng/l and a weekly 5 point calibration with at least one calibration point at less than 20 ng/l.

IMPLEMENTATION PROBLEMS/FIELD CHANGES

For the most part, the planned program and procedures were implemented in the field and required no significant changes. Necessary changes were due primarily to encountering contamination at unexpected concentrations or locations. These sources and resultant changes included:

- Rinsate samples of the sand pack material indicated the presence of hexachloro compounds. The natural sand material was replaced by sterile glass beads. The beads were shown to be essentially free of hexachloro compounds by rinsate sample analyses.
- Initially, kerosene was used as the decontamination solvent for well casings and drilling tools. However, sources of kerosene that were used for decontamination were contaminated with hexachloro compounds in the range of 20 μ gle. After this discovery, kerosene was no longer used for the decontamination of drilling equipment.
- The first decontamination water source was contaminated with low levels (hundreds of ng/l) of hexachloro compounds at concentrations greater than 100 ng/l. Several sources were analyzed and rejected before a clean decontamination water source was found.

We originally planned that only decontaminated stainless steel bailers would be in contact with water during development. The hose between the bailer and the pump was to remain above the water within the well. During development of the first well, it became apparent that the flow of water using this scheme was too slow to lift the heavy sediments from the screened area of the wells. After this discovery, decontaminated pump intake hoses were allowed to contact the well water. The intake end of the bailers was placed into the sediments at the bottom of the wells so that the sediment at the base of the wells could be withdrawn directly. This led to more rapid and more complete development and rinsing of the wells.

In addition to the above procedural changes, the schedule

changed greatly from the plans. Decontamination procedures for equipment and materials for each 40-ft deep well took 8 hr initially, decreasing to about 6 hr once the drilling crews became familiar with procedures. Adding to the time required to perform the sensitive decontamination procedures was the time required to scrub the sticky clays from the equipment between the drilling of successive wells. Also, due to the extreme care being taken to purge and sample the wells, a two-man crew could sample only two wells per day compared to the anticipated four wells per day.

RESULTS OF INVESTIGATION

Laboratory Results

In general, the WCAS was able to achieve QA criteria throughout the program. One problem did arise with reported concentrations of the target compounds in laboratory blanks. Normally, if the concentration of a compound in a sample is less than five times the compound's concentration reported in the laboratory blank, the sample results are rejected for that compound. This criterion was exceeded numerous times during the investigation.

One approach considered for data use was to simply report results as being above or below the criterion concentration (for HCB, 21 ng/l). Below that concentration, it would be assumed that site-related contamination was absent. This approach was rejected, since it did not take actual experimental error into account. As an alternative to this approach, laboratory results, including blank, rinsate and duplicate sample results, provided a reasonable idea as to what measured baseline level of contamination could be considered as suggestive of real groundwater contamination and which could not. Observed bailer blank concentrations were compared to well-casing rinse and gravel-pack rinse results; the highest of these was selected as the baseline for HCB or other contaminants. Therefore, results were evaluated with this baseline concept in mind. This was true even though the baseline concentration changed during the study.

Another problem resulted from a low concentration carryover contamination between samples. Midway through the investigation, a sample was obtained from an on-site well that had shown only low levels of contamination when analyzed previously. During this investigation, however, the sample concentrations were: HCE: 3,400,000 ng/l, HCBD: 1,300,000 ng/l and HCB: 110,000 ng/l. These concentrations saturated the GC column and laboratory test equipment and considerable effort was required to clean all the equipment so it could be used again.

The analyses performed following this sample, including laboratory and field blanks, reported elevated levels of contamination. The first field blank following the contaminated sample detected HCB at a concentration of 150 ng/l while the first laboratory blank detected HCB at 13 ng/l. The concentrations of contaminants reported in the blanks fell gradually, with the final field blank having an HCB concentration of 7 ng/l and the final laboratory blank having an HCB concentration of 2 ng/l. These blank concentrations elevated the baseline against which sample results were compared.

Confidence in data quality was enhanced by splits of selected samples analyzed by another laboratory under contract to potentially responsible party (PRP) industries. This laboratory did not analyze the highly contaminated sample, and thus had no carryover problem. The carryover problem was shown to be minor considering the laboratory split data and therefore the confidence in the data remained high.

Groundwater Contamination

Ten "ultra-clean" monitoring wells were installed around the site. As planned, the first ring of wells was installed 0.5 mi from the site. Due to property restrictions, however, only five wells were installed on this ring instead of the planned six. Water samples from these wells showed very low (less than 21 ng/l) concentrations of hexachloro compounds; for this reason, the second ring of wells was installed adjacent to the site boundary. Five wells were installed on the second ring which was not circular but instead followed the site boundary. (Figure 3).



Figure 3 Monitoring Well Plan—Location of Sampling Wells

All samples collected from ultraclean wells had reported concentrations of less than the criterion of 21 ng/l, except one sample collected form well P7 and one analysis of a sample from well P8. These were samples collected at nearly the same time as the highly contaminated sample referred to elsewhere in this paper. Although P9 is downgradient from the site, a second sample from it had a reported HCB concentration of only 12 ng/l. Table 2 shows all results for samples from ultraclean wells.

Table 2 Groundwater Quality Results 40-Ft Sand Zone

	<u>Concentration (ppt)</u>					
Well No.	Hell Type	HCE	HCHD	HCB		
P-1	Ultraclean	ND	ND	14		
P-2	Ultraclean	ND	ND	10		
P-3	Ultraclean	ND	ND	10		
P-4	Ultraclean	ND	ND	10		
P-5	Ultraclean	ND	ND	7		
P-6	Ultraclean	ND	ND	13		
P-7	Ultraclean	2	3	30		
P-0	Ultraclean	260	470	120		
P-8 (resample)	Ultraclean	3	6	12		
P-9	Ultraclean	16	70	20		
P-10	Ultraclean	3	11	נו		
W-10	PVC	42	400	490		
W-12	PVC	ND	140	1100		
W-14	PVC	ND	20	140		
₩-16	PVC	ND	62	100		

Several samples from wells immediately adjacent to the site (P6 through P10) had higher reported concentrations of hexachloro compounds than similar results from the more distant wells (P1 through P5), especially for HCE and HCBO. Whether this reflects true contamination in shallow groundwater near the site or rather a bias effect due to accumulation of contamination in laboratory or field equipment is open to question, since reported concentrations in both laboratory and field blanks became greater as the study proceeded. Re-sampling of all ultraclean wells in random order may be the best way to resolve this question.

Results for samples from PVC wells installed during the RI are presented in Table 2. The difference in results when compared to samples from the ultraclean wells is obvious. The specific source(s) of artifact contaminants in the RI well samples could not be determined. Drilling method, well materials and decontamination procedures all may contribute to downhole contamination. Earlier contaminant migration assessments based on ultra-sensitive analyses on samples from these wells were inaccurate. It is likely that some or perhaps all of the contamination measured in the shallow groundwater water samples was not siterelated. Hydrogeologic data obtained during this investigation indicated that the effects of on-site leachate mounding were less than originally anticipated. Water flow in the 40-ft zone appears not to oscillate but to flow continuously to the east. For this reason, the wells located west of the site should not be contaminated due to the Cleve Reber site. The samples from these wells had reported hexachlorobenzene concentrations in the range of 10 ng/l.

Since analysis of samples from the ultraclean wells installed west of the site reported concentrations of HCB of about 10 ng/l, we concluded that either the sand zone has been contaminated by hexachlorobenzene from other sources (apparently unlikely) or that the reported concentrations are false positives due to experimental error. In either case, the site is contributing very little, if any, contamination to the 40 ft sand zone.

Well Construction Comparison

Two monitoring wells were installed using ultraclean installation techniques adjacent to wells previously installed during the R1. The previously installed wells were constructed using PVC pipe, wash boring methods and a non-tested source for decontamination and drilling water. These wells also supplied samples subjected to the initial low level analyses. Positive results from those analyses were the driving force for this investigation. The new ultraclean wells were constructed using stainless pipe and screen, dry auger drilling methods nd strict decontamination procedures. Paired PVC and ultraclean wells were sampled simultaneously using identical sampling techniques as outlined in this paper to assess the difference in water quality results between adjacent wells. The results of the samples are presented on Table 3, while the locations of the wells are shown on Figure 3.

Table 3 Comparison of Well Installation Techniques and Materials

140))	1 111	Transition	Concenta	ppt)	
Pair	No.	Installed	HCE	HDED	HCB
1	₩-14	RI	ND	20	140
	P-6	Low Level	ND	ND	13
2	₩-10	RI	42	400	490
	P-9	Low Level	16	70	20

Concentrations (ng/l)

The difference in results is obvious between the PVC wells installed during the RI and the ultraclean wells installed during the low level investigation; the results clearly demonstrate the problem with normal drilling and well installation practices for this type of investigation. The specific source(s) of contaminants in the RI well samples could not be determined. The drilling method, well materials, sampling techniques and decontamination procedures all may contribute to well sample contamination. Contamination assessments performed using the ng/l level analyses for HCB from the RI wells were inaccurate.

Well Development and Flushing Effects

As discussed previously, the hexachloro contaminants of concern in this study have high octanol-water partition coefficients and can be expected to attach preferentially to sediments rather than stay in solution. Consequently, it was realized that effective development of the wells (to flush out sediment remaining from drilling activities) was especially important in this low level study of groundwater contaminants. Several of the existing wells sampled were not extensively developed during the RI in an attempt to minimize the effects on the in-place permeability of the soils adjacent to the well. These wells were redeveloped during this investigation and sampled. Two ultraclean wells and two RI wells were sampled several times over an extended period of time to determine the effect of total purge flow on measured sample contaminant concentrations. The results of these samplings are presented on Table 4. Since all wells were purged of at least five well volumes of water before each sampling, the progressively lower sample results suggest a significant effect of total purge flow on reported contaminant concentration. The results are more dramatic for the RI wells, but are significant even for the ultraclean wells. Although the effects of time and increased purge volume cannot be accurately separated they are expected to be negligible, since degradation of these compounds in groundwater should be very slow.

CONCLUSIONS

As a result of this careful study of the Cleve Reber Site to detect

 Table 4

 Water Quality Results After Multiple Well Samplings

Well No.	Investigation Program Installed	Date Sampled	Hexachlorobenzene Conc. (ppt)
W-1	RI	1/22	1,900
		1/30	800
		2/6	600
		4/19 (1 PM)	650
		4/19 (4 PM)	220
₩-14	RI	1/20	440
		2/4	140
P-1	Low Level	1/29	18
		2/6	14
		4/9	9
P-8	Low Level	4/11	120
		4/20	12

low level hexachloro chemicals, we concluded that:

- It is possible to perform an investigation to measure low concentrations of contaminants in groundwater and obtain useable results. The cost-effectiveness of the methods is questionable and the procedures are time intensive.
- Laboratory QA can be maintained to obtain usable results at low ng/l concentrations. However, a rigorous program of laboratory blanks and method validation is necessary to assess the extent of laboratory-related contamination.
- The installation of wells to measure contaminants at ng/l levels is possible, but requires rigorous procedures including:
 - Extensive decontamination
 - Careful drilling with continuous professional oversight
 - Testing all well materials at the criterion concentration
- Samples suspected as being highly contaminated should not be analyzed using the equipment utilized for low concentration analyses without first screening on less sensitive equipment. Samples should be collected and analyzed in the order of leastexpectation to greatest-expectation that contaminants are present.
- Large numbers of field QA samples (blanks, duplicates and spikes) are especially desirable to improve confidence in low level contaminant data. Additionally, replicate wells (two or more wells installed near each other and screened in the same interval) should be installed to quantify well related random contamination; if possible.
- Contamination related to well materials, drilling methods, decontamination fluids and sampling methods may become especially significant during an investigation of low level contaminant concentration. Fluid and rinsate samples must be sampled rigorously to determine whether these sources of contamination are compromising the investigation. The investigator must be willing to change materials and fluids to eliminate identified contamination sources.

Extensive well development (high turbulence and high total purged volume of water) is essential for accurate measurement of groundwater quality, especially in low level investigations.

A Cost-Saving Statistically Based Screening Technique for Focused Sampling Of a Lead-Contaminated Site

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ABSTRACT

High concentrations of lead in soils along an abandoned railroad line prompted a remedial investigation to characterize the extent of contamination across a 7-acre site. Contamination was thought to be spotty across the site reflecting its past use in battery recycling operations at discrete locations. A screening technique was employed to delineate the more highly contaminated areas by testing a statistically determined minimum number of random samples from each of seven discrete site areas. The approach not only quickly identified those site areas which would require more extensive grid sampling, but also provided a statistically defensible basis for excluding other site areas from further consideration, thus saving the cost of additional sample collection and analysis. The reduction in the number of samples collected in "clean" areas of the site ranged from 45 to 60%.

INTRODUCTION

In December 1985, WAPORA surveyed the extent of reported lead contamination of railroad property in Troy, Ohio, formerly owned by the Cleveland, Cincinnati, Chicago and St. Louis Railway (CCC & St. L). Until 1978 a portion of this property was utilized for automobile and industrial battery salvage operations. Batteries to be salvaged at a nearby concern were received at a common railroad loading dock, off-loaded and trucked to the salvage site. Reclaimed lead was packed in 55-gal drums, trucked to the loading dock and shipped to processing facilities. During these activities, materials containing lead were spilled in the loading dock area and the general environs of the former depot.

Lead concentrations in excess of 380,000 ppm were measured at the site in an initial investigation by the U.S. EPA's TAT contractor. Interviews with area residents, many of whose residences abutted the railroad property, provided a vague picture of the physical layout of the battery recycling operation. More accurate delineation of the areas of contamination prior to sampling was precluded by a fire after the recycling operation ceased. The fire destroyed structures that might have provided further clues and caused major portions of the site to be regraded, thus obliterating other indicators. An overview of the site showing the seven areas of interest (including north/south components) is provided in Fig. 1.

THE SAMPLING APPROACH

The description by area residents of the lead recycling operations suggested that some portions of the site, notably areas 1 and 3, might contain no lead. There were several reasons for thinking so:

- Major elements of the recycling operation had been located in areas 2 North, 4 North and, as was eventually discovered, area 5
- Lead compounds left to weather at a site are usually highly insoluble and are often not susceptible to wind dispersion over large distances
- No visual observations of lead deposition were made in areas 1 and 3, in contrast to the other areas

It was felt that a preliminary screening of the site using a statistically defensible approach might eliminate areas 1 and 3 from the more exhaustive grid sampling necessary in the other areas, thus conserving the private client's sampling budget.

The method ultimately selected considered all points within a sampling areas to be at equal risk for lead contamination. For each of the seven areas flanking the CCC & St. L railroad mainline, a sampling grid was selected with grid size based on the likelihood of gross contamination (i.e., smaller grid sizes in areas known to be used for battery recycling or scrap loading). The intersections of the grid lines (nodes) were each identified by a number. The total number of grid nodes within an area became the sample population at risk, referred to as N. At this point, the statistical approach begins to deviate from straightforward grid sampling.

To minimize the sampling burden, a subgroup, n, is selected to have a high probability to include sample locations of maximum concentration (highest 10%). The probability of missing locations within the highest 10% concentration levels becomes α . The correct sample size for subgroup n is expressed by the followingequation:

$$Po(N, \tau, n) = \alpha \tag{1}$$

where:

- N = total number of grid intersections for area of concern
- n = subgroup sample size
- τ = percentage of maximum concentration (highest 10%)
- α = the probability of missing locations within maximum concentration percentage, τ (0.05)

The solutions for various sample populations, concentration subgroups and allowed probability have been previously published. For this project, the most stringent criteria were utilized as presented in Table 1.



Figure 1 Lead Sampling Project: Location of Sampling Areas 1-5

Table 1Sample Size for Top 10%

 $(\tau = 0.1)$, confidence = 0.95 and α = 0.5 (use n = N if N \leq 11) Total locations N = 19-21 22-24 25-27 28-31 32-35 36-41 42-50 > 50

Required no. of

sample points								
(n) =	15	16	17	18	19	20	21	29

With the total potential sampling locations (N) and the number of sample points (n) established, random selection for the identifier numbers of the actual sampling points was accomplished by computer. Utilization of computerized random selection eliminated both individual and site bias.

APPLICATION OF THE METHOD

The statistical methodology was employed independently on each of the seven site areas. In areas 1 through 4 North and South, the sampling results corroborated the statements of area residents:

- Areas 1 and 3 generally were indicated to be clean areas in both memory and analytical result. Only 5 out of 38 samples showed lead contamination at levels from 500 ppm to 1,000 ppm. Subsequent sampling of the two areas as a check on the approach revealed no pattern of more extensive contamination in either area.
- Areas 2 North and South showed evidence of moderate contamination. In area 2 North, for example, 5 of 21 samples showed contamination at levels in excess of 500 ppm; 3 of the samples tested in excess of 1,000 ppm. Again, subsequent sampling and analysis confirmed a pattern of limited contam-

ination as shown in Fig. 2.

- Areas 4 North and South were indicated to be among the most heavily contaminated in both interview and analytical result. In Area 4 North, for example, about half of the samples obtained in the initial pass through the area tested at levels in excess of 1,000 ppm with one as high as 6,000 ppm.
- Area 5 was a surprise. Interviews with residents had suggested that Area 5 would look more like Areas 1 and 3 (i.e., lightly, if at all, contaminated). However, 10 of the 29 samples analyzed showed levels over 500 ppm with 6 at levels greater than 1,000 ppm. One sample tested at 24,000 ppm. These results indicated Area 5 should undergo more intensive sampling, a process that confirmed a pattern of heavy contamination of the area. Fig. 3 shows the pattern of contamination eventually revealed and highlights the samples selected statistically for analysis.

CONCLUSIONS

Application of the statistical sampling screen to the site facilitated delineation of the overall picture of site contamination in a rapid and cost-effective manner. Areas, such as Areas 1 and 3, where light contamination was suggested by the results of the statistical sampling approach were confirmed through subsequent sampling to be, indeed, only lightly contaminated with lead. These areas required far less excavation than the others. Using the statistical approach in Areas 1 and 3 in lieu of full grid sampling, cut sampling and analysis costs by 45% and 60% respectively.

The benefit of this approach, however, was perhaps best indicated in its detection of Area 5 as an area of potentially serious contamination, an indication confirmed by subsequent detailed sampling. Prior to sampling, anecdotal evidence had suggested that Area 5 could be largely ignored.



Figure 2 Lead Sampling Project: Area 2 North

In summary, the method has several features that make its application at a site useful for broad-brush delineation of gross contamination:

- Samples are taken at standard grid nodes so that all data obtained remains useful even if full grid sampling is subsequently implemented (i.e., neither data nor dollars are wasted)
- Cost savings achieved over full grid sampling and analysis of "clean" areas are in the ratio of $\frac{N-n}{n}$, a value ranging from

from about 27% to 50% for grids having up to 50 nodes and increasing for higher numbers of grid nodes



Figure 3 Lead Sampling Project: Area 5

- Laboratory turnaround time can be significantly shortened due to the smaller number of samples required, thereby facilitating a (better informed) secondary sampling effort following up on first phase results
- Different confidence levels for results can be obtained using different numbers of samples

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U.S. EPA Guidelines for Risk Assessment

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ABSTRACT

In recent years, the U.S. EPA has moved toward a risk assessment/risk reduction framework to make regulatory decisions. The Agency has taken a number of steps to assure the quality and consistency of the risk assessment component of those decisions. The first, and perhaps most important, is the development of Agencywide risk assessment guidelines. Five guidelines have been proposed and are nearing the completion of the public- and peer-review process. They are: carcinogenicity, mutagenicity, developmental toxicity, chemical mixtures and exposure. The provisions of the five guidelines are discussed in the context of the four components of risk assessment.

Other activities designed to assure quality and consisteny in risk assessments, reduce uncertainty in risk assessment, ensure a more efficient information exchange about risk and risk assessment and develop the appropriate oversight mechanisms also are discussed. These include additional guidelines, the Risk Assessment Forum, risk assessment research, the Integrated Risk Information System, the Hazard Assessment Notification System, and the Risk Assessment Council.

INTRODUCTION

One of the U.S. EPA's key factors in developing a pollution control strategy is evaluating scientific information to assess the risk from an environmental insult or the degree that the risk may be reduced under any particular control scenario. As a result, risk assessment is increasingly important to the regulatory process. It is clear that the distinction between risk assessment and other parts of the regulatory decision process needs to be carefully and comprehensively defined. This regulatory decision process was basically defined several years ago by the National Academy of Sciences (NAS) and can include legal, economic, political and social factors as part of the management of risks determined by the risk assessment process (1) (Figure 1).



Figure 1 Elements of Risk Assessment and Risk Management

During the past decade, the U.S. EPA has moved vigoriously to a risk assessment/risk management/risk reduction framework for making regulatory decisions. As a consequence, the assurance of quality and the consistency of assessments have become important Agency issues.

A number of steps have been taken to help achieve these goals of quality and consistency; perhaps the most important step is the development of Agencywide assessment guidelines. The U.S. EPA had developed such guidelines in the past: carcinogenicity in 1976 and 1980, systemic toxicants and mutagenicity in 1980 and exposure assessment in 1983 (2,3,4,5). In January, 1984, the U.S. EPA began intensive work on six new or revised guidelines: carcinogenicity, mutagenicity, reproductive toxicity (subdivided into individual guidelines for developmental toxicity and male and female reproductive toxicity), systemic toxicants (e.g., target organ toxicants), chemical mixtures and exposure assessment ⁶.

The first stage for each guideline was the development of drafts by Agency-wide work groups of scientists. These drafts then were circulated to scientists from academia, other governmental agencies, industry and public interest groups.

Using this procedure, five guidelines (carcinogenicity, mutagenicity, developmental toxicity, chemical mixtures and exposure) were proposed for public comment ^{7,8,9,10,11}. After the public comments were received, Agency staff evaluated the comments, suggested revisions and sent the proposed guidelines and the evaluation of comments to special review panels of the Science Advisory Board (SAB). The review panels and the Executive Committee concurred on the guidelines subject to certain revisions and subsequently concurred on the revisions^{12,13}. The proposed risk assessment guidelines are in the final stages of review and clearance and will, upon completion, be published in the Federal Register ^{14,15,16,17,18}.

The U.S. EPA's guidelines set forth internal Agency procedures that will:

- Promote consistency across U.S. EPA risk assessments by developing common approaches to risk assessment
- Promote the quality of the science underlying the U.S. EPA risk assessments by using a consensus approach (discussed below) where appropriate
- Clarify the U.S. EPA's approach to risk assessment by informing the public and the regulated community about the process used to evaluate scientific information

The guidelines *are not* regulations: in fact, they are intentionally flexible to encourage the use of all data and the appropriate scientific methods and judgments. The guidelines can, however, influence the regulatory process by:

- Making the U.S. EPA's risk assessments more consistent and of higher technical quality
- Familiarizing risk assessors throughout the country with the U.S. EPA's approach
- Making it possible for scientists to plan their experiments to collect the information that U.S. EPA scientists would like to have available when conducting a risk assessment

Finally, these guidelines are intended to be evolving documents. They are being updated, even now, as the science base relating to risk assessment leads to new understanding of the effects of toxic substances or to a reduction of the uncertainty inherent in the risk assessment process.

General agreement on the need for risk assessment guidelines does not exist. Some scientists have argued that articulation of guidelines is inappropriate and that every situation should be evaluated on a case-by-case basis. They believe that this case-bycase approach is necessary because of the complexity of the scientific issues and their concern that it is not easy to develop or follow general rules. On the other hand, others prefer detailed guidelines that take risk assessors through each step of the process and spell out specific approaches or scientific conclusions. As in most disagreements, there is a mddle group wishing to develop a general logic for the kinds of information needed and to articulate appropriate methods for assessment and evaluation. In this approach, the guidelines are intended to be tools in the hands of skilled scientists; they encourage the evaluation and use of all the available information on a case-by-case basis.

COMPONENTS OF RISK ASSESSMENT AND THEIR RELATIONSHIP TO THE GUIDELINES

In discussing risk assessment and risk management, the NAS divided the process of risk assessment into four components¹:

- Hazard Identification—the determination of whether a particular chemical is or is not causally linked to particular health effects
- Dose-Response Assessment—the determination of the relation between the magnitude of exposure and the probability of occurrence of the health effects in question
- Exposure Assessment—the determination of the extent of human exposure before or after application of regulatory controls
- Risk Characterization—the description of the nature and often the magnitude of human risk, including attendant uncertainty To the extent possible, the U.S. EPA's guidelines follow the Academy's definitions. The following sections describe each in

greater detail and show how the guidelines relate to them.

HAZARD IDENTIFICATION

The hazard identification component of a risk assessment consists of a review of relevant biological and chemical information bearing on whether or not an agent may pose a specific hazard. Sometimes, there is enough information available for the qualitative evidence to be combined into a formal weight-of-evidence determination.

For example, in the guidelines for carcinogen risk assessment 7,14 , the following information is evaluated to the extent that it is available:

- · Physical/chemical properties and routes and patterns of exposure
- Structure/activity relationships
- · Metabolic and pharmacokinetic data
- The influence of other toxicologic effects
- Short-term tests
- · Long-term animal studies
- Human studies

Once these data are reviewed, the animal and human data are divided separately into groups by degree of evidence:

- Sufficient evidence of carcinogenicity
- Limited evidence of carcinogenicity
- Inadequate evidence
- No evidence of carcinogenicity

The animal and human evidence then are combined into a weightof-evidence classification scheme similar to the one developed by the International Agency for Research on Cancer.¹⁹ This scheme gives more weight to human evidence when it is available. The scheme includes the following groups:

- Group A human carcinogen
- Group B probable human carcinogen
- Group C possible human carcinogen
- Group D not classificiable as to human carcinogenicity

• Group E - evidence of non-carcinogenicity towards humans

To some degree, these are arbitrary divisions along a continuum; therefore, categories should not be overinterpreted. The attached matrix (Table I) shows how the human studies and long-term animal studies are combined to derive the first approximation of the overall weight-of-evidence classifications. Other types of evidence then are used to adjust the first approximation upwards or downwards as appropriate.

Table I Illustrative Categorization of Evidence Based on Animal and Human Data.¹⁴

		ANIMAL EVIDENCE					
EVIDENCE	SUFF IC IENT	LIMITED	INADEQUATE	DATA	EVIDENCE OF NO EFFECT		
		_					
SUFFICIENT	*	*	•	•			
LIMITED	83	81	61	51	61		
				_			
INADEQUATE	82	C	D	0	Ð		
NO DATA	82	c	0	0	E		
EVIDENCE OF NO EFFECT	82	c	0	D	£		

NOTE: The above assignments are presented for illustrative purposes. There may be mances in the classification of both animal and human data indicating that different categorizations that those given in the table should be assigned. Furthermore, these assignments are tentative and may be modified by ancillary evidence. In this regard all refevant information should be evaluated to determine if the designation of the overall weight of evidence needs to be modified. Relevant factors to be included along with the turnor data from human and animal studies include structureactivity relationships, short-term test findings, results of appropriate physiological, biochardian and toxicological observations and comparative metabolism and pharmacokinetic studies. The name of these findings may cause an adjustment of the overall categorization of the weight of evidence.

In the case of mutagenicity risk assessment,^{8,15} the goal is to assess the likelihood that a particular chemical agent induces heritable changes in DNA and the likelihood that the chemical will interact with human germ cells.

Evidence that an agent induces heritable mutations in human beings could be derived from epidemiologic data indicating a strong association between chemical exposure and heritable effects. It is difficult to obtain such data, however, because any particular mutation is a rare event and only a small fraction of the estimated thousands of human genes and conditions currently are useful as markers in estimating mutation rates.

Therefore, in the absence of human epidemiologic data, it is appropriate to rely on data from experimental animal systems so long as the limitations of using surrogate and model systems are clearly stated. The universality of DNA and the interest in the possible causal relationship between mutagenesis and cancer induction are partly responsible for the development of a large number of both in vitro and in vivo mutation tests which may be used to evaluate the potential mutagenic activity of specific agents. the practical implication is that the available data for any set of chemicals are extremely variable, thus precluding a precise scheme for classifying chemicals as potential human germ-cell mutagens. A rankordered scheme of categories of evidence hearing on potential human germ-cell mutagenicity has evolved. The highest category is reserved for human epidemiologic data, recognizing that no such data currently are available. There are five other categories (in descending order) based on the premise that greater weight is placed on tests conducted in germ cells than in somatic cells, on tests performed in vivo rather than in vitro, in eukaryotes rather than prokaryotes and in mammalian species rather than in submammalian species. Additionally, there is a category for defining a nonmutagen, and there is a category for insufficient information to make a qualitative decision.

- The specific statements of the eight categories are:
- Positive data derived from human germ-cell mutagenicity studies, when available, will constitute the highest level of

evidence for human mutagenicity

- 2. Valid positive results from studies on heritable mutational events (of any kind) in mammalian germ cells
- 3. Valid positive results from mammalian germ-cell chromosome aberration studies that do not include an intergeneration test
- 4. Sufficient evidence of a chemical's interaction with mammalian germ cells, together with valid positive mutagenicity test results from two assay systems, at least one of which is mammalian (in vitro or in vivo). The positive results may both be for gene mutations or both for chromosome aberrations; if one is for gene mutations and the other for chromosome aberrations, both must be from mammalian systems
- 5. Suggestive evidence of a chemical's interaction with mammalian germ cells together with a valid positive mutagenicity evidence from two assay systems as described under 4, above. Alternatively, positive mutagenicity evidence of less strength than defined under 4, above, when combined with sufficient evidence for a chemical's interaction with mammalian germ cells.
- 6. Positive mutagenicity test results of less strength than defined under 4, combined with suggestive evidence for a chemical's interaction with mammalian germ cells
- 7. Although definitive proof of non-mutagenicity is not possible, a chemical could be classified operationally as a nonmutagen for human germ cells if it gives valid negative test results for all end points of concern
- 8. Inadequate evidence bearing on either mutagenicity or chemical interaction with mammalian germ cells

In the guidelines, developmental toxicity includes adverse effects on the developing organism that may result from exposure prior to conception (in either parent), during prenatal development or postnatally to the time of sexual maturation^{9,16}. The major manifestations of developmental effects include death of the developing organism, malformation, altered growth and functional deficiency. The term teratogenicity refers primarily to malformations and is a subclass of developmental toxicity.

Short-term and in vitro tests, which frequently are used for assessing risks from suspect carcinogens and mutagens, are not apropriate approaches for assessing developmental toxicity because the developing organism is such a complex system. Instead, bioassays and human epidemiologic data are the primary sources of information used. The primary biological assays involve treatment of animals during organogenesis and evaluation of the offspring at term. These types of evaluations also may be done as part of a multigeneration study.

The kinds of evaluations that are made in the U.S. EPA's hazard identification/weight-of-evidence determination include, as with all such evaluations:

• Quality of the date

- Resolving power of the studies; that is, consideration of the significance of the studies as a function of the number of animals or subjects
- Relevance of route and timing of exposure
- Appropriateness of dose selection

and, more specifically in the case of developmental toxicity, an evaluation of the information for a series of end points that may include:

- In the developing animal
- deaths
- structural abnormalities
- growth alterations
- functional deficiencies in the developing organism
- In the maternal animal
 - fertility
 - weight and weight gain
 - clinical signs of toxicity
 - specific target organ pathology and histopathology

In the case of chemical mixtures^{10,17}, the U.S. EPA conducts its hazard identification by considering the weights-of-evidence for

the mixture's component chemicals. Occasionally, and especially for complex mixtures, the evidence for a health hazard comes directly from studies on the mixture itself. Information on the mixture itself, however, must be carefully reviewed for evidence of masking of one toxic end point by another. For example, when one of the component chemicals is a suspect carcinogen but the data show marked toxicity in major organs (e.g., liver, kidney) and no indication of cancer, there is the possibility that other toxic effects may mask the evidence of carcinogenicity. The hazard identification then would suggest no cancer risk at any dose when, in fact, there could be significant risk of cancer at doses below the threshold for systemic toxicity.

Exposure assessment usually is a separate step in the risk assessment process; the exposure guidelines are discussed in a later section of this document. For mixtures, however, the exposure information must be considered to determine the chance that chemical interactions in the environment could produce new chemicals, over time or during transport, with different types of health hazards resulting. This concept is discussed more fully in the next section.

DOSE-RESPONSE ASSESSMENT

Classically, there are two general approaches to dose-response assessment depending on whether the health effects are threshold or nonthreshold. For threshold effects, discussed later in this section, the assessment estimates the point below which we do not expect a significant adverse effect. For nonthreshold effects, an attempt is made to extrapolate response data from doses in the experimental range to response estimates in the dose ranges typical of most environmental exposures. The largest number of such doseresponse extrapolations have been performed in the field of carcinogen risk assessment; therefore, the cancer guidelines give the most detailed guidance on dose-response assessment^{7,14}. These guidelines include the kinds of evidence that should be used in the dose-response evaluation, such as:

• If available, estimates based on human epidemiologic data are preferred over estimates based on animal data.

• In the absence of appropriate human studies, data from animal species that respond most like humans should be used.

• The biologically acceptable data set from long-term animal studies showing the greatest sensitivity generally should be given the greatest emphasis.

• Data from the exposure route of concern are preferred to data from other exposure routes; if data from other exposure routes are used, the considerations used in making route-to-route extrapolations must be carefully described.

• When there are multiple tumor sites or multiple tumor types, each showing significantly elevated tumor incidence, the total estimate of carcinogenic risk is estimated by pooling, i.e., counting the number of animals having one or more of the significant tumors.

• Benign tumors generally should be combined with malignant tumors for risk estimates.

Another major consideration is the choice of the particular mathematical model used for low-dose extrapolation. Different extrapolation models may fit the observed data reasonably well, but may lead to large differences in the projected risk at low doses. In keeping with the recommendations of the Office of Science and Technology Policy,²⁰ the Agency will review each assessment as to the evidence on cancer mechanisms and other biological or statistical evidence that indicates the biological suitability of a particular extrapolation model. A rationale will be included to justify the use of the chosen model. In the absence of adequate information to the contrary, the linearized multistage procedure will be employed. The linearized multistage procedure is recognized as leading to a plausible upper limit to the risk that is consistent with some proposed mechanisms of carcinogenesis.

Additional issues are species- and route-extrapolation of the doses. Currently, the U.S. EPA adjusts animal doses by the ratio of animal-to-human surface areas. The evidence in support of this approach is not strong, and research is in progress to improve the method. Route extrapolation is used when the only available data are for a route different from the route of concern.

In the present case of mutagenicity risk assessment^{8,15}, doseresponse assessments can only be performed using data on germinal mutations induced in intact mammals. The morphological specific locus and biochemical specific locus assays can provide data on the frequencies of recessive mutations, and data on heritable chromosome damage can be obtained from the heritable translocation test. As in carcinogen risk assessment, the Agency will strive to use the most appropriate extrapolation models for risk analysis and will be guided by available data and mechanistic considerations in this selection. However, it is anticipated that for tests involving germ cells of whole mammals, few dose points will be available to define dose-response functions, and a linear extrapolation will therefore be used. The Agency has recognized that pioneering work in the field of molecular dosimetry ultimately may lead to useful extrapolation models.

The other major approach to dose-response assessment concerns effects which the Agency refers to as systemic toxicants or noncarcinogenic health effects (see below). Although this particular area is not yet covered by guidelines (they are still being developed), it is appropriate to discuss the general approach. The Agency usually calculates what is called Reference Dose (RfD), that is, the dose below which we do not expect a significant risk of adverse effects. The reference does is related to the more familiar concept of the Acceptable Daily Intake (ADI), but strives to remove the elements of risk management from the process. At present, the U.S. EPA is not sure at which point above the RfD there will be a significant adverse health effect. The dose-response evaluation is done in the following way. The literature is examined to determine both the critical toxic effect (that is, the adverse effect that first appears in the dose scale as the dose is increased) and the highest dose at which the effect does not occur (often called the highest No-Observed-Adverse-Effect-Level or NOAEL). This NOAEL is divided by an uncertainty factor which generally ranges from 10 to 1,000; the uncertainty factor is composed of a series of factors, each representing a specific area of uncertainty inherent in the data available.

The RfD calculation is a generic calculation for most toxicants considered to have thresholds. In addition, much work is being conducted in an attempt to develop more quantitative approaches for dose-response assessment for reproductive and developmental toxicants both within and outside of the U.S. EPA.

The dose-response procedures described in the chemical mixtures guidelines are a bit different^{10,17} In this case, guidance is provided to combine several different types of information on the mixture of concern as well as on the mixture's components. If dose-response data are available for the mixture itself, such data are used and other Agency risk assessment procedures would apply to the mixture as a whole. If data are not available on the specific mixture, it may be appropriate to infer information from sufficiently similar mixtures. When neither is available, the guidelines suggest using what is called dose or response addition, appropriately modified if interactions between components (such as synergism) can be quantified. When interactions cannot be quantified and when the component chemicals are toxicologically similar, strict dose addition is used. For most threshold pollutants this means dividing each estimated intake level by its RfD and summing each of these quotients to calculate a hazard index. When the hazard index is much greater than one, a significant risk might be expected. When the hazard index is near one, each case needs to be considered individually.

For carcinogens and for dissimilar systemic toxicants that have dose-response data, response addition is used so that, at typical environmental levels, the excess risks for each component chemical are summed to reach an overall risk estimate. Again, interactions need to be considered, and we must recognize the added uncertainty in the assessment. The Agency intends to investigate this and other problems involving mixtures that contain carcinogens over the next few years.

EXPOSURE ASSESSMENT

From the titles of the various risk assessment guidelines, it is

clear that four of the five relate to health effects; in those cases, which have been presented previously, discussions of hazard identification and dose-response assessment are appropriate. In contrast only, one guideline discusses exposure assessment.

The Proposed Guidelines for Exposure Assessment¹¹ and the Guidelines for Estimating Exposures¹⁸ provide a procedural framework on how best to estimate the degree of human contact to a chemical. The major areas to be evaluated when estimating exposures are:

- Source assessment—a characterization of the sources of contamination
- Pathways and fate analysis—a description of how a contaminant may transport from the source to the potentially exposed population
- Estimation of environmental concentration—an estimate using monitoring data and/or modeling of contamination levels away from one source where the potentially exposed population is located
- Population analysis—a description of the size, location and habits of potentially exposed human and environmental receptors
- Integrated exposure analysis—the calculation of exposure levels and an evaluation of uncertainty

An integrated exposure assessment quantifies the contact of an exposed population to the substance under investigation via all routes of exposure and all pathways from the sources to the exposed individuals.

Generally, exposure estimates may be presented by expressing the magnitude and duration of an individual event of exposure or by expressing potential lifetime exposure. For example, evaluations of acute or subacute effects, such as developmental effects, would use the magnitude of exposure per event or several events over a short period of time. On the other hand, assessments of carcinogenic risk often consider the daily average exposure calculated over a lifetime. The nature of the toxic effect being evaluated in the risk assessment will determine the appropriate length of exposure presented.

For most risk assessments involving chronic exposure, exposure (mg/kg/day) is calculated as a dose averaged over the body weight (kg) and lifetime (days):

Average Daily	=	Total Dose	(1)
Lifetime Exposure		Body Weight × Lifetime	(-)

The total dose (mg) can be expanded as follows:

Total Contaminant Contact Exposure Absorption(2) Dose = Concentration × Rate × Duration × Fraction

The four parameters in equation (2) are defined as follows:

- Contaminant concentration represents the concentration of the contaminant in the medium (air, food, soil, etc.) contacting the body; typical units are mass/volume or mass/mass.
- Contact rate is the rate at which the medium contacts the body (through inhalation, ingestion or dermal contact); typical units are mass/time or, for dermal contact, volume/surface area.
- Exposure duration is the length of time for contact with the contaminated.
- Absorption fraction is the effective portion of total contaminant contacting and entering the body. Entering the body means that the contaminant crosses one of the three exchange membranes: alveolar membrane, gastrointestinal tract or skin.

The six factors given in equations (1) and (2) must be known (or estimated) in order to estimate exposure. Research is in progress to better define how to estimate each of these factors for humans as well as test animals.

RISK CHARACTERIZATION

In our guidelines, the risk characterization step is a summing discussion in which information is put together in a useful way. This means that the risk characterization contains not only a risk estimate for a specific exposure, but also a cogent summary of the biological information, the assumptions used and their limitations and a discussion of both qualitative and quantitative uncertainties in the risk assessment.

In the case of cancer, mutagenicity and chemical mixtures guidelines^{7,8,10,14,15,17}, the risk characterization specifically consists of the dose-response extrapolation information as well as the associated weight-of-evidence determination from the scale or table contained in the guidelines. For mixtures^{10,17}, the weight-of-evidence covers three areas: health effects information, toxic interactions and exposure estimates.

In the case of the exposure assessment guidelines, a specific mathematical technique has been developed to assess uncertainty^{11,18}. In this case, the probability distributions estimated for the uncertainty around each compartment in the calculation are entered into a computer program, and the probability distribution of the results of the exposure assessment can then be calculated or estimated.

SYSTEMIC TOXICANTS

The last of the six original areas of guidelines development is for systemic toxicants. Guidelines have not yet been prepared because it is difficult to reach consensus for such a broad area. The U.S. EPA essentially includes chemicals causing a variety of health effects other than cancer, mutagenicity and specific acute effects under the umbrella of systemic toxicants. This umbrella clearly covers many end points and many different target organs that could be considered for any one chemical.

In the absence of consensus procedures, each Program Office at the U.S. EPA has approached the problem in different ways²¹. Examples include evaluating a specific adverse health effect rather than determining the critical health effect (the adverse health effect occurring at the lowest dose and assessing risk for less than lifetime exposure rather than determining a lifetime chronic Acceptable Daily Intake (ADI) or Reference Dose (RfD). In addition, Program Offices have used different approaches for dealing with uncertainty. Some offices estimate a lifetime chronic RfD based on uncertainty factors tied to the available information and then establish criteria based on that RfD. Some offices calculate a Margin of Safety between the highest No-Observed-Adverse-Effect-Level (NOAEL) of the critical effect and the estimated exposure and then evaluate that margin specifically in terms of the chemical of interest and its expected exposure pattern. Some offices estimate an appropriate degree of protection on a case-by-case basis, using their best technical and scientific judgment. Finally, some programs have developed their own quantitative techniques for extrapolating or interpolating across data gaps; few of these have yet gained general acceptance within the Agency.

The guidelines development effort has postponed the Agency achieving consensus on the entire list. Generic issues resolved in this RfD review process will then form the basis for the guidelines on systemic toxicants.

OTHER GUIDELINES PROJECTS

The Science Advisory Board (SAB) reviewed the proposed guidelines and suggested the development of two additional documents: guidelines for making and using environmental measurements in exposure assessments, and a technical support document for the guidelines on chemical mixtures. Work on those projects is under way. In addition, a document is being developed to focus on areas in need of research in developmental toxicology.

Work also is continuing on two other guidelines, one for the Assessment of Risk to the Male Reproductive System and the other for the Assessment of Risk to the Female Reproductive System. In addition, Agency staff is working on guidelines for the assessment of systemic toxicants and is planning guidelines for the assessment of ecological risk and the appropriate use of metabolism and pharmacokinetic data and models.

RISK ASSESSMENT FORUM

Risk assessment guidelines are only one tool used to make decisions. The guidelines, therefore, are only one part of the procedures to make the Agency's decisions more consistent and reliable. Another mechanism is the Risk Assessment Forum. For any one issue, the available information may lead to differing scientific interpretations; these differences need to be resolved. In addition, there may be areas that the guidelines presently do not cover but which need immediate or short-term resolution.

Finally, as scientific theories develop and change or as experimental techniques and risk assessment assumptions change, there needs to be a way to augment or amend the Agency's risk assessment policies. The Agency, therefore, decided to establish a standing group of senior scientists who would meet regularly to provide a "forum" for those kinds of discussions and decisions^{6,22}. This new organization is not intended to be involved in routine quality assurance of risk assessments; it will only become involved where significant scientific uncertainties or science policy issues need resolution.

The Forum assists the U.S. EPA's risk assessment process in several ways:

It analyzes scientific information and science policy issues for use in Agency risk assessment

- It develops risk assessment guidance not covered by the guidelines
- It recommends revisions to the guidelines whenever such revisions appear to be necessary
- It mediates inter-office differences on risk assessment issues
- It recommends appropriate research to reduce uncertainties in risk assessment

REDUCING UNCERTAINTIES

One of the critical needs in risk assessment is reducing the uncertainty of the estimates. The U.S. EPA is undertaking several activities to do that. First, the Agency has planned three workshops. One, a "Consensus Workshop on the Relationship of Maternal and Developmental Toxicity" was held recently to address issues of interpretation of data in the area of developmental toxicity when toxicity to the maternal animal may also be apparent²³.

Another workshop to be held this fall is on the use of pharmacokinetic models in risk assessment. The goal of this workshop is to identify the basis on which these models are formulated and the assumptions and data that are necessary for their use. This workshop will address the practical application of pharmacokinetic principles and models to improve risk assessment.

Finally, there will be a workshop this fall on cancer research needs to help the Agency identify the key areas of risk assessment research for carcinogenicity and to establish a list of priorities for that research. The authors anticipate that these latter two workshops will be the first of a fairly extensive series on workshops in these areas.

OTHER ACTIVITIES

The U.S. EPA was one of the pioneers in developing and adopting risk assessment methods. For the first 10 yrs, this meant developing the techniques, applying them and then attempting to reach consensus about their appropriate use. That effort has culminated in the proposed publication of the five guidelines and in the continued plans for guideline development and risk assessment research.

It is now appropriate to consolidate that effort by ensuring a more efficient information exchange about risk and risk assessment and by developing the oversight mechanisms to ensure consistency and high technical quality in the Agency's risk assessments.

One area of concern is quality assurance of the hazard and risk evaluations developed within various Program Offices; for example, the work of the RfD review group referred to earlier. A review group has been working since early 1985, and its first group of RfDs is nearing approval for inclusion in Agency information systems (see discussion below). A similar review process is being established for carcinogen risk estimates. Another area of concern is the development of appropriate information exchanges about risk assessment activities in the U.S. EPA in order to identify the hazard assessment activities under way within the Agency and prevent possible duplication, to increase the awareness of ongoing activities of interest to various Program Offices and to improve Hazard Assessment Notification System in which Program and Regional Offices will list all hazard assessments in a data base and report on work that is under way or anticipated.

Another such Agency-wide activity is the Integrated Risk Information System (IRIS). One of the many problems encountered by risk assessors both inside and outside of the U.S. EPA is obtaining coherent information about existing Agency risk conclusions useful for formulating risk assessments. The results of carcinogen bioassays, dose-response calculations, NOAELS, RfDs and other parameters for a large number of chemicals exist, but this information has never been integrated into an easily accessible, centralized information base.

Information in IRIS will be organized in a readily accessible electronic mail system on a chemical-by-chemical basis. Information will be provided by four continuing efforts, each of which will be reviewed periodically for consistency and quality prior to entry into the system. As a chemical-based system IRIS will collect information for a compound and construct a file in which all numbers fit into a particular format.

Information provided by the four continuing efforts, will periodically supply updated assessments and information to the central IRIS management unit. One effort will contribute reviewed RfDs, while a second will do the same for cancer risk estimates. The third component will list acute hazard information that the Agency has recently published²⁴ and the fourth will provide risk management numbers Agency-wide (Reportable Quantities, National Ambient Air Quality Standards, Water Quality Criteria, Maximuim Contaminant Levels, etc.). Information from these four projects will be merged to produce a file consisting of a series of chemical-specific documents. The user then will be able to call up a chemical by name and review all of the pertinent U.S. EPA summary material.

Other computer-related projects include the development of toxicity data bases. The furthest along is "Studies on Toxicity Applicable to Risk Assessment." This data base is unique because it contains toxicity data for each dose group and includes programs for calculating and presenting the data in human equivalent terms by using the extrapolation models and time-weighted-averaging methods discussed previously. A second project is a mixtures data base, currently containing summary information about more than 1,200 studies on toxic interactions such as synergism and antagonism. Both data bases are being prepared so that they can be accessible to the public to further the improvement of risk assessment methodology.

Finally, the Agency has established the Risk Assessment Council to provide oversight for the development, review and implementation of U.S. EPA policy related to risk assessment.

CONCLUSION

Risk assessment at the U.S. EPA has evolved from an art developed by a small group of people discussing primarily cancer to a general analytic and decision tool used by many people in many programs across the Agency. Furthermore, many of the U.S. EPA's statutes are now predicted on a risk reduction basis, which requires more and better health risk and exposure analyses. Since the possibility of overlapping and conflicting analyses exists, a larger Agency program is necessary to review risk assessments in general, to oversee the process and to develop more detailed guidelines. The structures to assure this quality and technical consistency are now evolving within the Agency. Therefore, as risk assessment becomes more sophisticated, as more risk assessments are performed and as the need for assurance of quality and consistency is increased, the Agency will develop guidelines for more end points, add more detail to existing guidelines, strengthen the management procedures to resolve scientific disputes, publicize those resolutions, and maintain the appropriate degree of oversight. This process will result in the development of better risk assessments with less overall uncertainty and, ultimately, better protection of public health.

DISCLAIMER

The views expressed in this paper are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.

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A Comparative Evaluation of Methods for Determining Alternative Concentration Limits

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ABSTRACT

Alternative concentration limits (ACLs) provide a means of establishing cleanup levels for site restoration. Derivation of an ACL requires determination of two numbers, an effects criterion (EC) and an exposure factor (EF). The EC represents the concentration at the point of exposure and reflects the contaminant's intrinsic toxicity. The EF represents the degree to which the contaminant concentration will be reduced in moving from the source to the point of exposure (i.e., the ratio of source concentration to exposure concentration). The EF is often a composite factor combining dilution, dispersion, degradation and attenuation on soils and aquifer media. The product of the EC and EF represents the maximum permissible concentration at the source area or the allowable cleanup level.

This paper provides a comparative discussion of methods which can be employed to derive values for EF. Specific approaches include analysis of monitoring data, the use of tracers and the use of mathematical models. The advantages, disadvantages and costs of each approach are discussed, and general guidelines are offered to select methods on a site-specific basis. Key determinants in the selection of an approach include the existence and quality of a monitoring well system, the physical/chemical properties of the contaminants and the complexity of the groundwater system at the site.

INTRODUCTION

The passage of CERCLA, promulgation of the National Contingency Plan (NCP) and amendments to RCRA in 1984 have raised considerable debate over the issue of "How Clean is Clean" with respect to corrective and remedial actions. While the U.S. EPA has not chosen to promulgate specific standards for site cleanup residuals, its growing use of risk assessment and risk management has provided the framework for a definitive approach on a site-specific basis. In particular, the agency has espoused the concepts of acceptable risk and probable exposure levels based on fate and transport considerations between the source and the receptor.

The use of risk assessment for selecting restoration levels was illustrated early in the CERCLA program with the Exposure-Response Analysis method.¹ In this approach, acceptable site residual levels are derived from a health-based concentration goal. The former is larger than the latter in recognition of dilution and attenuation which will occur during transit. The ratio of the former to the latter is a quantitative measure of dilution and attenuation factors for a given site. The U.S. EPA similarly acknowledges dilution and attenuation by allowing ACLs for site restoration levels which are higher than, but based on, health criteria, i.e., restoration levels are derived after allowance for concentration reduction during transport. As with the Exposure-Response Analysis method, the development of safe ACL values depends on the successful selection of the dilution/attenuation or exposure factor and the health-based effects criteria.

Development of defensible effects criteria for a number of pollutants based on toxicological data presently is being conducted by the U.S. EPA. Determination of the former for sitespecific cases is the subject of the following discussion, which characterizes the relative merits and deficiencies associated with different methods currently available. For purposes of organization, alternative methods have been grouped into three categories: passive empirical (monitoring data), active empirical (tracers) and theoretical (modeling).

PASSIVE EMPIRICAL METHODS

Passive methods involve the analysis of monitoring data to determine the degree of concentration reduction that will occur between the point of release and the point of exposure. In the ideal case, monitoring wells already would exist at the contaminated site and at several points downgradient, including the compliance point. Concentrations of the contaminant of interest would be measured at each well. The ratio of the source concentration and compliance point concentration represents the attenuation undergone by the contaminant while in transit. As such, the ratio constitutes the desired EF.

Clearly, the monitoring approach represents an accurate and inexpensive means of determining an EF under favorable circumstances. If monitoring wells are already in place, the incremental costs amount to those for analyses (which are likely to be required anyway). Many times, however, circumstances are not ideal. Common difficulties include those stemming from improper well location and inadequate plume development. These difficulties are discussed below.

Improper Well Location

If wells are not available at the source and at the point of compliance, the EF cannot be directly calculated. Two potential solutions are available. The most straightforward involves completion of monitoring wells at the required points. However, this approach can be expensive. For sites which are poorly characterized, a number of wells may have to be installed to accurately define the source of contamination, both areally and vertically. In cases where the plume is broad or multiple potable wells need to be protected, a number of compliance point wells may be required. This approach is contingent on an adequate knowledge of the geohydrologic setting to designate the compliance points for protection of all threatened receptors. The approach offers the advantage of providing wells which subsequently can be used to monitor the adequacy of corrective or remedial actions.

The second approach can be implemented if there are a number of monitoring wells proximate to and surrounding the points of interest. In this case, geostatistical methods are used to estimate the contaminant concentrations and uncertainty levels near the source and points of compliance. Mapping the concentrations provides a means of determining the probable range of concentrations which would be measured in a properly located monitoring well at each point of interest. If applicable, this approach is often less costly than construction of additional wells and has the added advantage of quantifying uncertainty. Even if additional wells are required, geostatistical analysis of existing monitoring data is often valuable for determining new well locations.

Inadequate Plume Development

Direct use of monitoring data will not be possible if the contaminant of interest has not reached the compliance point or has not reached steady-state conditions between the source and the compliance point. In either case, comparison of monitoring data would produce an inordinately high EF. The first condition can be identified easily when the contaminant of interest does not appear in samples from the compliance point. The second condition may not be as easy to identify without time sequence data establishing a constant ratio between well head concentrations over a period of a year or more. Once again, some knowledge of the geohydrologic setting is desirable to help establish the likelihood that the plume has reached steady state or to identify the required period of observation to make that determination.

If plume development is inadequate for all species in a discharge, the monitoring approach will not work in the short term. However, if plume development is complete for constituents other than those of concern, alternatives are available. For instance, if a contaminant of like adsorption and degradation potential has reached a steady state, it can be used to develop the EF by analogy. More commonly, if a conservative, mobile species has reached steady state, concentration data for it can be used to quantify the contribution of dilution and dispersion to the overall EF. If adsorption and degradation prolperties for the contaminant of interest are well characterized, EF can be increased accordingly with simple algorithms. Chloride is a particularly good conservative species for this purpose. Under proper circumstances, sulfate, nitrate, sodium, bromide or fluoride also may be employed. The analog approach is inexpensive to perform, but requires the presence of the conservative species in the overall plume at levels distinguishable from background.

ACTIVE EMPIRICAL METHODS

Active approaches to determining an 1:1- parallel the passive options but involve the intentional release of a tracer material to delineate groundwater travel times and paths. Most active systems require the same network of release and monitoring wells as passive systems and, therefore, encounter the same costs and drawbacks related to improper well location. The unique feature of active systems, the introduction of the tracer, offers both advantages and disadvantages to the overall activity.

The advantage of an active tracer stems from the analyst's ability to select a tracer with specific transport properties. Ideally, one would specify a nontoxic tracer with attenuation and degradation properties identical to those of the contaminant of concern. Recent work with fluorocarbons has been very successful in developing a variety of tracers with a spectrum of attenuation properties.

The disadvantage of active tracers is the need to wait for the tracer to move from the source to the monitoring well. In slowly moving groundwaters, the time delay will be larger than waiting for the contaminant to reach the monitoring wells. In such a case, passive monitoring becomes more economical. To circumvent the time problem, nonattenuating tracers can be introduced to elucidate dilution. Absorption, degradation and other attenuation mechanisms then can be accounted for with simple algorithms. Various agents are available as conservative tracers (i.e., tritium, chlorides and nonreactive fluorocarbons). Additionally, monitoring well locations can be moved backward to accelerate tracer tests. The data obtained then can be extrapolated forward to the compliance point. This accommodation adds uncertainty with respect to the linearity of the dilution phenomenon from the monitoring point on out to the compliance point.

An interesting modification to direct tracing approaches involves the use of a tracer which can be remotely monitored without wells. Electromagnetic induction (EMI) measures in situ conductivity in the earth. When intervening clay layers or metallic objects do not interfere, remotely-sensed conductivity can map the existence of saline plumes in groundwater or of freshwater in a groundwater brine. Therefore, if groundwater is low in conductivity, a brine solution (e.g., sodium chloride) could be added at the source and monitored remotely. When mapped, periodic measurements would provide a good indication of plume speed, dilution and plume size over time. Freshwater could be injected into a brine system and similarly tracked. In both cases, the tracers (brine or freshwater) would be conservative and factors other than dilution and dispersion would have to be considered separately.

The problems associated with use of tracers, namely the necessary time delays, can be avoided with proper planning in RCRA programs. In particular, if waste materials are intentionally spiked with conservative tracers at known levels prior to disposal, existing monitoring wells will provide an early warning that corrective action is needed as well as the necessary data to calculate the dilution portion of the EF. If the tracer were carefully selected, it also could reduce monitoring costs significantly.

THEORETICAL METHODS

Theoretical methods for establishing exposure factors can be classed under the general term mathematical modeling. While the word modeling often raises images of sophisticated numerical constructs and high costs, it is important to note that models can consist of a wide variety of tools that simulate reality. They may be as simple as a single equation or as complex as a massive computer program. The level of complexity should be dictated by the requirements of the problem.

In general, mathematical models can be grouped into three broad categories: simple algorithms, analytical models and numerical models. Algorithms may define a single phenomenon such as one-dimensional flow under set conditions of head, conductivity and porosity. Analytical models generally accommodate a number of phenomena under prescribed boundary conditions and homogeneous properties. Numerical models are the most flexible of the three and, therefore, can accommodate heterogeneity and complex boundary conditions. Costs and input data requirements increase with the level of sophistication. Similarly, within each group there are different levels of flexibility and sophistication available at increasing levels of cost.

The advantage offered by modeling is the ability to predict forward without the time delays inherent in monitoring or tracer approaches. Modeling also may be possible without construction of new monitoring wells. However, well data are required for the necessary inputs to the modeling process. Sites with no existing wells will require well construction to obtain the data needed to calibrate the model. In this regard, theoretical and empirical methods will incur similar costs. Modeling may reduce the number of wells required and, more importantly, can assist in determining whether existing data represent a steady-state plume development or a transient state. Perhaps the greatest advantage of modeling is the ability to evaluate the utility of proposed corrective/remedial actions as well as develop exposure factors for an array of compliance points. When tracers or monitored constituents have attenuation properties different from those of the contaminant of concern, the use of algorithms to accommodate those differences constitutes modeling.



Figure 1 Decision Tree for Developing an Exposure Factor to Derive Alternative Concentration Limits

In addition to groundwater transport models, geochemical models also may be useful for establishing ACLs, particularly with inorganic contaminants. The value of geochemical models arises for contaminants whose concentrations in groundwater are controlled by geochemical reactions, particularly dissolution/ precipitation reactions. In cases where contaminant concentrations are solubility limited, there is no fixed relation between the concentrations at the source and compliance point. Evaluation of the geochemistry at the site is necessary to determine whether the effects criterion will be exceeded.

The disadvantages of modeling arise from input data and resource needs. Since these needs are commensurate with the complexity of the model applied, they will vary between sites. There is also a perception problem associated with models. With strictly empirical approaches, one need only assure the quality of the data collected. With modeling, it is necessary to verify the model itself as well as the input data. Because models are often very technical, their use and interpretation requires special training. In turn, they often are viewed with suspicion by nonmodelers.

If modeling is selected as the best approach for deriving an exposure factor, the analyst still may be faced with the need to select a specific computer code. The U.S. EPA recently has developed model selection criteria for use in conducting exposure assessments. The guidelines accompanying these criteria will be of great value to less experienced modelers.

CONCLUSIONS

As indicated in the previous sections, there are a number of approaches which can be taken to select an exposure factor during the derivation of an ACL. Each approach has advantages and disadvantages based on the conditions at the site of concern and the problem set at hand. In general, the analyst should seek to select the most accurate, least costly approach feasible for a given site. Because the relative accuracy and costs will vary among the alternatives, selection is accomplished best using a logic tree evaluation, as illustrated in Figure 1.

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Risk Assessment for Underground Storage Tanks

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ABSTRACT

Risk is an issue of growing importance in both public and private sectors. Each has been faced with the task of examining the environmental and public health risks associated with underground storage tanks. Such risk assessments usually end with a decision as to what action, if any, should be taken to mitigate existing or potential problems. These decisions are based on many quantitative and nonquantitative variables. This paper describes one methodology involved in conducting risk assessment.

The process starts by compiling factual information relevant to an underground tank system. This process is called risk analysis. In the next step, risk assessment, the completeness of the information, its uncertainty and its applicability to the system and location are put into perspective through a numerical rating methodology. The objective of the assessment is to arrive at a numerical rating for each system. Using this numerical rating, the decision maker can develop a relative ranking of systems. Ideally, the rank ordering of the systems will correlate closely with the actual health and ecological risks. The key is to manage these risks at a minimum cost while protecting the environment. Because resources are limited, the ranking of systems will aid the decision maker in setting priorities to address those problems that offer the greatest reduction in risk for the money spent.

INTRODUCTION

Cleanup of a leaking tank system can cost millions of dollars. Because of the potential for huge direct and indirect costs of a leaking underground storage tank, it is imperative to have a program to assess risks involved with operating and maintaining such a system. With the increase in awareness of environmental sensitivity in recent years, the field of Risk Assessment has taken on increased importance. In the most general sense, Risk Assessment involves the evaluation of the potential impact of an underground storage tank leak. The negative impacts due to a storage loss might include not only environmental damage, but also economic loss and legal liability. Such liabilities can be caused by on-site soil or groundwater contamination, off-site contaminant migration, contamination of drinking water supplies or generation of potentially explosive vapors, just to mention a few possibilities. By conducting an early risk assessment, a company can implement preventative measures which are generally less costly than after-the-fact cleanup procedures. Clearly, the assessment of risk prior to incidents can be a valuable planning tool.

Risk Assessment can be performed in many different formats. One method of evaluating risk is based on Risk Assessment and Management (RAM) which is patterned after the Air Force Hazard Assessment Rating Methodology (HARM) system. The objective of RAM is to assess any risks involved with current and past operations that fall under the Underground Storage Tank (UST) program. RAM will provide a relative ranking of tank systems as to their potential for leaking. It also will provide indicators for early detection and remedial action before a leak occurs. If a leak does occur, RAM will allow one to detect and intercept contaminants before damage is caused.

RAM is designed to quantify the risk of contamination through the application of a numerical rating. This is done to enable one to rank tank systems in a relative manner as to potential for leaking and subsequent potential for contaminating the environment, particularly water resources. Each assessment considers multiple parameters in order to rate a specific site. The standard methodology is designed to yield consistent results so that each site can be rated accurately against the rest. An accurate definition of the tank system and surrounding environment at a site is critical to Risk Assessment and Management Rating. By ranking the system, the manager will have a good indication as to which system should be given priority attention.

There will not be sufficient funds available to take care of all potential problems at the same time. Thus, it is prudent to have a risk assessment management program to prioritize sites and to expend funds on those sites where the greatest savings through leak prevention and detection can be achieved.

DESCRIPTION OF MODEL

The rating model described in this paper is referred to as the Risk Assessment and Management Rating Methodology (RAM). Like other site ranking models, the RAM rating model uses a scoring system to rank sites for priority attention (Fig. 1).



Figure 1 Risk Assessment and Management Rating Methodology Flow Chart

The model uses data readily obtained during the evaluation of past and current operations and field inspections. Scoring judgments and computations are easily made. In assessing the hazards at a given site, the model develops a score based on the physical characteristics of the system, the most likely routes of contamination and the worst hazards of the site. Sites are given low scores only if there are clearly no hazards at the site and the tank system is in very good condition.

This model considers five aspects of the hazards posed by a specific site:

• The physical characteristics of the system

- The possible receptors of the contamination
- The product and its characteristics
- Potential pathways for product contamination migration
- Product management practices

Each category contains a number of rating factors used in the overall Risk Assessment and Management rating.

The physical characteristics and receptors category ratings are calculated by scoring each factor, multiplying by a factor weighting constant and adding the weighted scores to obtain a total category score.

Pathway Category

The pathways category rating is based on evidence of contaminant migration or an evaluation of the highest potential (worst case) for contaminant migration along one of three pathways. If evidence of contaminant migration exists, the category is given a subscore of 80 to 100 points. For indirect evidence, 80 points are assigned and for direct evidence, 100 points are assigned. If no evidence is found, the highest score among three possible routes is used. These routes are surface water migration, flooding and

Table 1 Risk Assessment and Management Rating Methodology Form

NAME OF SITE _____ Date of operation of occurrence _____ LOCATION OWNER/OPERATOR TS/DESCRIPTION_ SITE BATED BY 1. PHYSICAL CHARACTERISTICS OF TANK SYSTEM PACTOR HAKINUH BATTING MULTI- FACTOR POSSIBLE BATING FACTOR SCORE (0-3) SCORE TARK

	Subtotals	276
N. MAINTENANCE AND REPAIR HISTORY		15
L. NOWITORING WELLS	4	12
K. RELEASE DETECTION	<u>s</u>	15
OTHER		
J. LOOSE FITTINGS/BREAKAGE		21
I. VISIBLE CORROSION	10	30
H. CATHODIC PROTECTION	6	18
G. PIPING COMPOSITION	10	30
P. AGE OF PIPING	, , ,	21
PIPING		
. VISIBLE CORROSION	10	30
D. CATHODIC PROTECTION	6	28
C. TANK COMPOSITION	10	30
L. SIZE	5	15
A. ACE		21

Phys. Char. Subscore: (100 x factor score subtotal/maximum score subtotal)

	FACTOR			HARINUN
BASTRO DAGES	PATING	MULTI-	FACTOR	PUSSIBLE
RATING FACTOR		PLIER	SUUL	
A. POPULATION WITHIN 1.000 FEET OF SITE		4		12
B. DISTANCE TO WEAREST WELL		10		30
C. LAND USE/ZOWING WITHIN 1 HILE RADIUS		3		9
D. DISTANCE TO RESERVATION BOUNDARY		6		18
E. CHITICAL ENVIRONMENTS WITHIN 1 MILE BADIUS				
OF SITE		10		30
F. WATER QUALITY OF WEAREST SURFACE WATER BODY		6		<u>18</u>
G. GROUNDWATER USE OF UPPERHOST AQUIFER		9		27
N. POPULATION SERVED BY SURFACE WATER SUPPLY				
WITHIN 3 MILES DOWNSTREAM OF SITE		6		18
I. POPULATION SERVED BY GROUNDWATER SUPPLY				
WITHIN 3 MILES OF SITE		. 6		16

Subtotels _____

180____

Receptors subscore (100 X factor score subtotal/maximum score subtotal)

groundwater migration. Evaluation of each route involves factors associated with the particular migration route. The three pathways are evaluated and the highest score among all four of the potential scores is used.

Product Characteristics Category

The product characteristics category is scored in three steps. First, a point rating is assigned based on an assessment of the product quantity and the hazard (worst case) associated with the site. The level of confidence in the information is also factored into the assessment. Next, the score is multiplied by a product persistence factor, which reduces the score if the product is not very persistent. Finally, the score is further modified by the physical state of the product. Liquid products receive the maximum score, while scores for sludges and solids are lower.

Summation

The scores for each of the four categories are then added together and normalized to a maximum possible score of 100. Then the product management practice category is scored. The final site score is calculated by applying the product management practices category factor to the sum of the scores for the other four categories. The higher the score, the more risk can be assumed.

III. PRODUCT CHARACTERISTICS

- A. Select the factor score based on the estimated quantity, the degree of hazard, and the confidence level of the information.
 - Product quantity (S = small, H = medium, L = large)
 - z. Confidence Level (C = confirmed, S = suspected
 - Hazard rating (H = high, H = medium, L = low)
 - Factor Subscore A (from 20 to 100 based on factor score matrix)
- B. Apply persistence factor

Factor Subscore & I Persistence Factor - Subscore B

_____× _____ * _____

c. Apply physical state multiplier

Subscore B I Physical State Multiplier - Product Characteristics Subscore

×.

IV.	PATHNAYS	

	FACTOR		HAXIHUH
	RATING	FACTOR	POSSIBL
BATING FACTOR	(0-3) MULTIPLIER	SCORE	SCORE

a. If there is evidence of migration of hazardous contaminants, assign maximum factor subscore of 100 points for direct evidence or 80 points for indirect evidence. If direct evidence exists then proceed to C. If no evidence or Indirect evidence exists, proceed to B.

Subscore

- Bate the migration potential for 3 potential pathways: surface water migration, flooding end groundwater migration. Select the highest rating and proceed to C.
 - 1. Surface water migration

Distance to Mearest Surface Water	8	24
Net Precipitation	6	18
Surface erosion		24
Surface permeability	6	16
Rainfall intensity	8	24
Subscore (100 % factor score subtotal/max	Subtotals imum score subtotal)	
Flooding	1	

۷.

з

Depth to groundwater	8	
Net precipitation	6	
Soil permeability	8	
Submurface flows		
Direct access to groundwater		

Subscore (100 x factor score subtotal/maximum score subtotal)

u. Highest pathway subscore.

Enter the highest subscore value from A, B-1, B-2, or B-3 above.

Pathways Subscore

.....

V. PRODUCT NANAGENERY PRACTICES

A Average the four subscores for physical characteristics, receptors, weste characteristics and pathways.

Physical Characteristics Receptors	
Patherays	
Totaldivided by 4 -	Gross Total Score

B. PRODUCT HARAGENERY PRACTICES FACTOR

The multiplier derived below is then applied to the total everage risk points (Gross Total Score) from Part & above:

For each of the eleven factors listed below, cumulatively add rating velues to get an aggregate total:

100005	NANAGENEET PRACTICES	RATING VALUE
1.	Liners in good condition	0.16
2.	Sound dikes and adequate freeboard	0.10
3.	Adoquete monitoring wells	9.05
4.	Satisfactory morgancy response procedures	0.10
5.	Procedures for filling tenks must have adoquate	
	procestions regarding spills and everflows	0.05
٤.	Effective delly inventory record	0.10
1.	fafoguards against product theft	8.65
۰.	Pariodic tank tooting for lasks	8.10
9.	Delly check of Lanks for water content	4.65
10.	Training program and employee cortification for	•.•.
	lookage tosting, opili control and margancy procedures	0.16
11.	Tanks not in service properly safeguarded or emptied	0.05
	Aggregate Totale	****
a	- Aggregate Total) - Product Henegement Practices Factor	

C. Grees Lotal Score I Product Management Practices Factor + Final Score

_____ I _____ * *********

	Tab	le 2	
Risk	Assessment	and	Management
Rat	ling Methodo	log	Guidelines

I. PHYSICAL CHARACTERISTICS CATEGORY

		Rating Scale Levels					
-	Rating Factors	0	!	2		Multiplier	
A .	Age of Tank	0-2 years	2 - 5	5 - 10	greater than 10	٦	
8.	Size	less than 500 gal	500-2,000	1,000 - 5,000	greater than 5,000	5	
c.	Tank Composition	0	Fiberglass (Non-Metallic)	Protected Steel	Unprotected Steel	10	
D.	Cathodic Protection	High Amount	Medium	Law	None	6	
E.	Visible Corrosion	None	Low	Nedium	High	10	
F.	Age of Piping	0 - 2	2 - 5	5 - 10	greater than 10	٦	
G.	Piping Composition	0	Fiberglass-PVC (Non-Metallic)	Protected Steel	Unprotected Steel	10	
H.	Cathodic Protection	High Amount	Medium	Low	None	6	
۱.	Visible Corrosion	None	Low	Med i um	High	10	
J.	Loose Fittings/Breakage	None	Low	Medium	High	٦	
K.	Release Detection	High Amount	Hed i um	Low	None	5	
ι.	Monitoring Mells	High Amount	Medium	Low	None	4	
Ħ.	Maintenance and Repair History	Excellent	Good	Fair	Poor	5	

II. RECEPTORS CATEGORY

	Kating Scale Levels					
	Rating Factors	0	1	2	3	Multiplier
Α.	Population within 1,000 feet (includes on-base facilities)	0	1 25	26 100	Greater than 100	4
B.	Distance to nearest water well	Greater than 3 miles	to 3 miles	3,001 feet to 1 mile	0 to 3,000 feet	10
C.	Land Use/Zoning (within I mile radius)	Completely remote (zoning not applicable)	Agricultural	Commercial or Industrial	Residential	3

	D.	Distance to Installa- tion boundary	Greater than 2 miles	I to 2	miles	1,001 mile	feet to I	0 to 1,000 feet	6
	E.	Critical environments (within 1 mile radius)	Not a critical environment	Natural	areas	Prist areas prese sence impor resou to co	ine natural , minor wetlands; rved areas; pre- of economically tant natural wrces susceptible ontamination	Major habitat of an dangered or threatened species; presence of recharge area; major wetlands.	IQ
	F.	Groundwater use of designation of nearest surface water body	Agricultural or industrial use.	Recreat gation ment of wildlif	ion, propa- and manage- fish and e.	Shell tion	fish propaga- and harvesting	Potable water supplies	6
	G.	Groundwater use of uppermost aquifer	Not used, other sources readily avaitable	Commerc trial, tion, v other w	ial, indus- or irriga- ery limited ater sources	Drink munic avail	ing water ipal water able.	Drinking water, no muni cipal water available; commercial, industrial, or irrigation, no other water source available.	- 9
	Η.	Population served by Surface water supplies within 3 miles down- stream of site	0	1 50		51	1,000	Greater than 1,000	6
	1.	Population served by aquifer supplies within 3 miles of site	0	I 50		51 -	1,000	Greater than 1,000	6
		. PRODUCT CHARACTERISTIC	25						
ļ	A-1	Product Quantity	_						
		s = Small quantity (500	0 - 1,000 gals)						
1		M = Moderate quantity ((1,000 - 10,000 gals)						
		L = Large quantity (gre	eater than 10,000 gals)						

- A-2 Confidence Level of Information
 - C = Confirmed confidence level (minimum criteria below)
 - ⁰ Verbal reports from Interviewer (at least 2) or written information from the records.
 - ⁰ Knowledge of types and quantities of products used by shops and other areas on base.
 - ⁰ Based on the above, a determination of the types and quantities of product at the site.

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11

11

11

			Rating Scale Levels	
Risk Category	0	!	2	3
foxicity	Sax's Level O	Sax'š Level	Sax's Level 2	Sax's Level 3
lgni fabili ty	Flash point greater than 200 ⁰ F	Flash point at 140 ⁰ F to 200 ⁰	Flash point less than 80 ⁰ F to 140 ⁰ F	Flash point less than 80 ⁰ F

S = Suspected confidence level

used at a site.

⁰ No verbal reports or conflicting verbal reports and no

O Logic based on a knowledge of the types and quantities of products generated at the base, and a history of past

product management practices indicate that these products

written information from the records.

Use the highest individual rating based on toxicity or ignitability and determine the risk rating.

Points		
3 2		

A-3 Risk Rating

III. PRODUCT CHARACTERISTICS (Continued)

Product Characteristic Matrix

Point	Product :	Confidence Level	Risk
Rating	Quantity	of information	Rating
100	ι	с	н
80	L	C	H
	Ň	c	H
70	ι	S	н
60	S	C	н
	H	с	M
50	ι	S	M
	ι	с	ι
	M	S	н
	S	с	Ħ
40	S	S	H
	м	S	н
	Ħ	С	ι
	ι	S	ι
30	S	с	L
	м	\$	ι
	S	<u>Ş</u>	M
20	S	S	ι

B. Persistence Multiplier for Point Rating

Persistence Criteria

Notes:

For a site with more than one hazardous product, the product

- quantities may be added using the following rules: ^o Confirmed confidence levels (C) can be added
- Suspected confidence levels (S) can be added
- Confirmed confidence levels cannot be added with suspected confidence levels

Product Risk Rating

⁰ Wastes with the same hazard rating can be added

Multiply Point Rating From Part A by the Following

⁰ Mastes with different hazard ratings can only be added in a downgrade mode, e.g., MCM + SCH = LCM if the total quantity is greater than 20 tons.

Example: Several products may be present at a site, each having an MCM designation (60 points). By adding the quantities of each product, the designation may change to LCM (80 points). In this case, the correct point rating for the product is 80.

Metals, polycyclic compounds and halogenated hydrocarbons	1.0
Substituted and other ring compounds	0.9
Straight chain hyrdrocarbons	0.8
Easily biodegradable compounds	0.4

C. Physical State Multiplier

Physical State	Multiply Point Total From Parts A and B by the following
Liquid	1.0
Sludge	0.75
Solid	0.50

IV PATHWAYS CATEGORY

A. Evidence of Contamination

Direct evidence is obtained from laboratory analyses of hazardous contaminants present above natural background levels in surface water, groundwater, or air. Evidence should confirm that the source of contamination is the site being evaluated.

Indirect evidence might be from visual observation (i.e., leachate), vegetation stress, sludge deposits, presence of taste and odors in drinking water, or reported discharges that cannot be directly confirmed as resulting from the site, but the site is greatly suspected of being a source of contamination.

B-1 POTENTIAL FOR SURFACE WATER CONTAMINATION

	Rating Scale Levels				
Rating Factors	0	<u> </u>	2		Multiplier
Distance to nearest surface water (includes drainage ditches and storm sewers)	Greater than I mile	2,001 feet to 1 mile	501 feet to 2,000 feet	0 to 500 feet	8
Net precipation	Less than -10 in.	-10 to + in.	+5 to 20 in.	Greater than -20 in.	6
Surface erosion	None	Slight	Moderate	Severe	8
Surface permeability	0% to 15% clay -2 (greater than 10 cm/sec)	15% to 30% clay -2 -4 (10 to 10 cm/sec)	30% to 50% clay -4 -6 (10 to 10 cm/sec)	Greater than 50% clay -6 (less than 10 cm/sec)	6
Rainfall intensity based on 1 year 24-hr rainfall	less than 1.0 inch	1.0-2.0 inches	2.1-3.0 Inches	greater than 3.0 inches	8

B-2 POTENTIAL FOR FLOODING

Floodplain	Beyond 100-year floodplain	ln 25⊶year flood- plain	ln IO-year flood- plain	Floods annually	I
		Rating	cale Leveis		
Rating Factors	0	l	22	3	Multiplier
B-3 POTENTIAL FOR GROUNDWA	TER CONTAMINATION				
Depth to groundwater	Greater than 500 feet	50 to 500 feet	ll to 50 feet	0 to 10 feet	8
Net precipiation	Less than -10 in.	-10 to +5 in.	+5 to +20 in.	Greater than +20 in.	6
Soil permeability	Greater than 50% clay -6	30% to 50% clay -4 -6	15% to 30% clay −2 −4	0%L to 15%L clay -2	8
	(greater than 10 cm/sec	:)	(10 to 10 cm/sec)	10 to 10 cm/sec)	less than 10 cm/sec)
Subsurface flows	Bottom of site greater than 5 feet above high groundwater level	Bottom of site occasionally submerged	Bottom of site frequently sub- merged	Bottom of site located below mean groundwater	8
Direct Access to ground- water (through faults, fractures, faulty well casi subsidence fissures, etc.)	No evidence of risk	Low risk	Moderate risk	High risk	8

V PRODUCT MANAGEMENT PRACTICES CATEGORY

A. This category adjusts the total risk as determined from the physical characteristics, receptors, pathways and product characteristics categories for product management practices and engineering controls designed to reduce this risk. The total risk is determined by first averaging the receptors, pathways and product characteristics subscores. Then from Part B below, a management factor is computed and subtracted from the number 1 to get a decimal multiplier.

B. PRODUCT MANAGEMENT PRACTICES FACTOR

The multiplier derived below is then applied to the total average risk points from Part A above:

For each of the eleven factors listed below, cumulatively add rating values to get an aggregate total:

PRODUCT	MANAGEMENT PRACTICES	RATING VALUE
١.	Liners in good condition	0.10
2.	Sound dikes and adequate freeboard	0.10
3.	Adequate monitoring wells	0.05
4.	Satisfactory emergency response procedures	0.10
5.	Procedures for filling tanks must have adequate precautions regarding spills and overflows	0.05
6.	Effective daily inventory record	0.10
7.	Safeguards against product theft	0.05
8.	Periodic tank testing for leaks	0.10
9.	Daily check of tanks for water content	0.05
10.	Training program and employee certification for leakage testing, spill control and emergency procedures	0.10
н.	Tanks not in service properly safeguarded or emptied	0.05
	Aggregate Totals	

(1 - Aggregate Total) = Product Management Practices Factor

The U.S. EPA's Methodology for Adjusting The Reportable Quantities of Potential Carcinogens

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ABSTRACT

CERCLA Section 102 designates a list of hazardous substances and establishes statutory reportable quantities (RQs) for them. The federal government must be notified whenever one of these substances is released in a quantity greater than or equal to its RQ. CERCLA gives the U.S. EPA the authority to adjust RQs as appropriate. The U.S. EPA is now about to adjust the statutory RQs of most potential carcinogens. To support this effort, the U.S. EPA's Carcinogen Assessment Group has developed a methodology for ranking potential carcinogens. This methodology is based on two factors—weight of evidence and potency—that the Carcinogen Assessment Group considers essential to describing a carcinogenic hazard. This paper describes the methodology and the supporting rationale.

INTRODUCTION

CERCLA Section 102 designates a list of hazardous substances and establishes statutory reportable quantities (RQs) for them. The federal government must be notified whenever one of these substances is released in a quantity greater than or equal to its RQ. CERCLA gives the U.S. EPA the authority to adjust RQs as appropriate.

No determination has been made that the release of a substance at or above its RQ will be hazardous. The RQ is merely a trigger for notification. Many considerations will affect the government's decision about whether and how it should respond to a particular release. The location of the release, its proximity to drinking water supplies or other valuable resources, the likelihood of exposure or injury to nearby populations, remedial actions taken by responsible parties and other factors must be assessed by the federal on-scene coordinator on a case-by-case basis.

By the end of 1986, the U.S. EPA will have promulgated or proposed three rules to adjust the statutory RQs of most of the 717 CERCLA hazardous substances. The first two rules deal with hazardous substances that are not potential carcinogens, and the third rule deals with the potential carcinogens. The first rule," published on April 4, 1985, adjusted the statutory RQs of 340 hazardous substances that are not potential carcinogens. On the same date, the U.S. EPA also published a Notice of Proposed Rulemaking for the second rule.² The final second rule, which will adjust the statutory RQs of another 102 hazardous substances, should be promulgated before this paper appears in print. Also anticipated is the Notice of Proposed Rulemaking for the third rule, which will adjust the statutory RQs of most potential carcinogens. The final third rule should be promulgated in 1988 after a review of public comment. The U.S. EPA's Office of Solid Waste and Emergency Response (OSWER) decided to separate the potential carcinogens in this manner so that the other statutory RQs could be adjusted while a methodology for ranking potential carcinogens is developed, the potential carcinogens are ranked and there is public comment on the methodology and rankings.

CERCLA gives the U.S. EPA wide discretion in adjusting RQs. The U.S. EPA has chosen to use the five RQ levels—1, 10, 100, 1,000 and 5,000 lbs—originally established pursuant to Section 311 of the Clean Water Act. RQs are adjusted after evaluating each hazardous substance for its intrinsic physical, chemical and toxicological properties. Six properties, called primary criteria, are considered: aquatic toxicity, mammalian toxicity, ignitability, reactivity, chronic toxicity and potential carcinogenicity. Each of the six primary criteria is ranked on a five-tier scale that corresponds to the five RQ levels. The lowest of these six tentative RQs becomes the hazardous substance's primary criteria RO.

After the primary criteria RQ is assigned, the hazardous substance is evaluated further for susceptibility to certain degradative processes. Three processes are considered: biodegradation, hydrolysis and photolysis. If a hazardous substance degrades relatively rapidly to form a less harmless substance, then its primary criteria RQ is raised one level unless the substance is also bioaccumulative, environmentally persistent, highly reactive or otherwise unusually hazardous. If a hazardous substance degrades to form a more harmful substance, then its primary criteria RQ is replaced by the RQ for the more harmful substance. This RQ, determined after considering the six primary criteria and three degradative processes, becomes the hazardous substance's adjusted RQ for the purpose of rulemaking.

OVERVIEW OF THE METHODOLOGY

To identify which CERCLA hazardous substances should be ranked on potential carcinogenicity, OSWER relies on four sources: annual reports on carcinogens from the National Toxicology Program, monographs of the International Agency for Research on Cancer, final determinations published by the U.S. EPA in the *Federal Register* that identify a substance as a potential carcinogen and determinations by the U.S. EPA's Office of Health and Environmental Assessment that a substance may be a potential carcinogen. If a substance is identified as a potential carcinogen, then its adjusted RQ is based on all six primary criteria. If a substance is not identified as a potential carcinogen, then its adjusted RQ is based on the other five primary criteria.

The U.S. EPA has decided to treat potential carcinogenicity with more caution than the other primary criteria. This decision recognizes a number of positions that the U.S. EPA has taken repeatedly with respect to cancer and is thought to be in concert with prudent public health concerns:

• Threshold levels of exposure, below which there is no risk of cancer, have not been demonstrated.^{3,4,5} Thus the release of

any quantity of a potential carcinogen may increase the risk of cancer in the exposed population. This is in contrast to most other toxic effects for which thresholds can be demonstrated.

- Cancer risks are considered to be cumulative.³ A number of small releases can be as serious as a single large release.
- Cancer is not immediately manifested.^{4,5} There is a latent period between exposure to a carcinogen and the manifestation of cancer that makes it impossible to directly observe carcinogenic risks from substances newly released into the environment. This period of delay is in contrast to acute toxic effects which are more immediately manifested.

Partly for these reasons, OWSER has decided to adopt a 100-lb maximum RQ for potential carcinogens, so the 1,000-lb and 5,000-lb RQ levels are not used for potential carcinogens. Because three RQ levels are left to be used, potential carcinogens are ranked on a three-tier scale (High, Medium and Low) that corresponds to RQ levels of 1, 10 and 100 lbs.

The U.S. EPA's Carcinogen Assessment Group (CAG), part of the Office of Health and Environmental Assessment, has developed the methodology for ranking the potential carcinogens High, Medium or Low. This methodology is based on two factors —weight of evidence and potency—that CAG believes are essential to describing a carcinogenic hazard. Weight of evidence is a qualitative evaluation of the strength of the case that a substance causes cancer in humans. Potency is a quantitative estimate of the strength of a substance to cause cancer. These two factors are evaluated separately and then are combined to arrive at the threetier hazard ranking. The rest of this paper describes these two factors and how they are combined.

WEIGHT OF EVIDENCE— THE QUALITATIVE PHASE

Weight of evidence is a qualitative evaluation of the strength of the case that a substance causes cancer in humans. Partly to encourage consistent evaluations, the U.S. EPA published its proposed guidelines for carcinogen risk assessment.³ These guidelines call for the evaluation of all pertinent human, animal and in vitro studies. The rest of this section is a paraphrase of the system for classifying the weight of evidence.

Evidence of carcinogenicity from human studies comes from case reports of individual cancer patients, descriptive epidemiologic studies and analytical epidemiologic (case-control and cohort) studies. Three criteria must be met before a causal association can be inferred between exposure and cancer in humans: there is no identified bias that could explain the association, the possibility of confounding has been considered and ruled out as explaining the association and the association is unlikely to be due to chance. The degree of evidence for carcinogenicity is then summarized as:

- Sufficient (there is a causal relationship)
- Limited (a causal interpretation is credible)
- *Inadequate* (chance, bias or confounding could not adequately be excluded, or there were few pertinent data)
- No data
- No evidence (no association was found in well-designed and well-conducted independent analytical epidemiologic studies)

Evidence of carcinogenicity from animal studies is summarized as:

- Sufficient—there is an increased incidence of malignant tumors in multiple species or strains, in multiple experiments or to an unusual degree with regard to high incidence, unusual site or type of tumor or early age at onset.
- Limited-the data suggest a carcinogenic effect but are limited

because the studies involve a single species, strain, or experiment and do not meet the criteria for sufficient proof; the experiments are restricted by inadequate dosage levels, inadequate duration of exposure, inadequate period of follow-up, poor survival, too few animals or inadequate reporting; or the studies show an increase in the incidence of benign tumors only.

- *Inadequate*—the studies cannot be interpreted as showing either the presence or absence of a carcinogenic effect.
- No data
- No evidence—there is no increased incidence of neoplasms in at least two well-designed and well-conducted animal studies in different species.

Based on the combined evidence for carcinogenicity for human and animal studies, a substance is classified into one of five weight-of-evidence groups:

- Group A-Human Carcinogen-sufficient human evidence
- Group B—Probable Human Carcinogen—limited human evidence, or sufficient animal evidence in the absence of sufficient or limited human evidence; this group is divided into two subgroups: usually Group B1 is reserved for substances with limited human evidence, and Group B2 for substances with sufficient animal evidence in the absence of sufficient or limited human evidence
- Group C—Possible Human Carcinogen—limited animal evidence in the absence of sufficient or limited human evidence
- Group D—Not Classifiable—inadequate human and animal evidence or no data
- Group E—Evidence of Non-Carcinogenicity for Humans—no evidence for carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies

All relevant supporting information then is evaluated to see if the overall weight of evidence should be modified. Relevant factors to be included along with the tumor information from human and animal studies are: structure-activity relationships; shortterm test findings; results of appropriate physiological, biochemical and toxicological observations; and comparative metabolism and kinetic studies. The nature of these findings may cause one to adjust the overall weight of evidence.

POTENCY—THE QUANTITATIVE PHASE

Potency is a quantitative estimate of the strength of a substance to cause cancer in humans. Potencies are calculated for substances in Groups A, B and C that have suitable dose-response data. Potencies are not calculated for substances in Groups D and E, since they are not properly called potential carcinogens.

A prime concern in ranking hazardous substances is the need for consistency and comparability across substances. In accordance with the U.S. EPA's proposed guidelines for carcinogen risk assessment' and with the U.S. EPA's practice in numerous risk assessments, the multistage model has been chosen for estimating potency. According to the multistage model with k stages, the lifetime increased cancer risk from a lifetime dose of D milligrams of carcinogen per kilogram of body weight per day is:

$$P(D) = 1 - \exp - (q_1 D + q_2 D^2 + \ldots + q_k D^k)$$
(1)

For adjusting statutory RQs, the potency is defined as the reciprocal of the estimated dose associated with a lifetime increased cancer risk of 10% (ED10). That is, the potency is 1/ED10 where P(ED10) = 0.10. This measure of potency has been chosen instead of the upper bound on the linear coefficient (q_1 *) that CAG regularly uses to estimate potency because:

- It is relatively insensitive to the choice of the dose-response model, so the potency rankings are not distorted by the choice of any particular dose-response model.
- It does not require extrapolation beyond the observed data, because a 10% response is usually within the observed range.
- It is a statistically stable estimate, in contrast to the measure q1*, which requires the use of upper bounds to ensure stability. (It should be noted that other elements of the methodology, such as the use of the most sensitive animal species, introduce non-statistical upper bounds into the potency estimate.)

The selection of dose-response data for fitting the multistage model follows the U.S. EPA's proposed guidelines. Human studies are preferred to animal studies, although they need to be considered case by case. Otherwise the data set from the longterm animal studies showing the greatest sensitivity is used, with due regard to biological and statistical considerations. Animals with one or more tumor sites or types showing significantly elevated tumor incidence are pooled, and benign tumors generally are combined with malignant tumors unless the benign tumors are considered to have the potential to progress to the associated malignancies. In the absence of comparative toxicological, physiological, metabolic and kinetic information, extrapolation to humans is made on the basis of body surface area. Finally, to adjust for the smaller number of tumors expected in a less-thanlifetime study, the potency is increased by the third power of the ratio of the animal's lifespan to the study's duration.

The potential carcinogens are classified into potency groups as follows:

- Group 1-1/ED10 above 100 (highest potency)
- Group 2—1/ED10 between 1 and 100
- Group 3-1/ED10 below 1 (lowest potency)

For some potential carcinogens, the dose-response data are not suitable for estimating potency. In most of these cases, the substance is assigned to Group 2 as if it had a mid-range potency. In a few of these cases, however, the data indicate a possibly high potency because every dosed animal developed cancer, so the substance is assigned to Group 1.

Because 1/ED10 is not the usual measure of potency, CAG has investigated how it is related to q_1^* , its usual measure of potency. If a straight line were drawn between the 10% response point and the origin, the slope of that line would be one-tenth of the value 1/ED10. Thus 1/ED10 should be approximately 10 times q_1^* , an upper bound on the slope. There are three reasons why this factor of 10 may not hold in general. Because the dose-response curve usually lies below this straight line at very small doses, the factor should be increased. Because q_1^* is an upper bound, the factor should be decreased. And because upper bounds to not always overestimate by the same amount, there should be some spread around the factor.

Empirical analysis of the CERCLA potential carcinogens shows that 1/ED10 is closely related to q_1^* . In Fig. 1, the logarithm of 1/ED10 is plotted against the logarithm of q_1^* for 86 substances where both could be computed independently from the same data set. (This excludes substances where the dose-response data are not suitable for estimating potency, where the potency is based on a related substance or where 1/ED10 is computed directly from l_1^* as estimated from a human study.) The logarithmic transformation is used to equalize the variances of estimates that range over several orders of magnitude. There is very little deviation from a straight-line fit; the correlation is 0.99. Linear regression yields:

$$\log 1/\text{ED10} = 0.8 + 1.0 \times \log q_1 * (R^2 = 0.99)$$
(2)

The result is equivalent to saying that 1/ED10 averages about 6 times q_1^* .

This close relationship between 1/ED10 and q_1^* demonstrates that a ranking of potential carcinogens based on 1/ED10 should agree with a ranking based on q_1^* . This agreement, together with the other advantages of 1/ED10 cited earlier, has led CAG to choose 1/ED10 as the measure of potency to be used in adjusting statutory RQs.



COMBINATION OF WEIGHT OF EVIDENCE AND POTENCY

L

Hazard rankings are based jointly on two factors—weight of evidence and potency—that CAG believes are essential to describing a carcinogenic hazard. Hazard rankings of High, Medium and Low are assigned so that the hazard ranking increases as either the weight of evidence or the potency increases. Table 1 shows how hazard rankings are assigned.



		Potency group			
		1	2	3	
	A	High	High	Medium	
eight-of- evidence group	B	High	Medium	Low	
	C	Medium	Low	Low	
	D	Not	azard rank	ing	
	Ε	Not	azard rank	ing	

Depending on whether a substance falls into potency groups l, 2 or 3, a hazard ranking of High, Medium or Low is assigned to Group B carcinogens. Hazard rankings are one level higher (High, High or Medium) for Group A carcinogens. This increased concern is justified because there is direct human evidence establishing that Group A substances cause cancer. Hazard rankings are one level lower (Medium, Low or Low) for Group C carcinogens. This reduced concern is justified because the evidence implicating Group C substances is less certain, as it may be either unreplicated or of marginal biological or statistical significance.

Before settling on these hazard ranking assignments, alternative ranking schemes were considered. Proposals that all Group A substances be ranked High or that all Group C substances be ranked Low were rejected because CAG believes strongly that potency is essential to describing a carcinogenic hazard. Similarly, a proposal to base hazard rankings on potency alone was rejected because CAG believes that weight of evidence must be considered as well. It is CAG's judgment that the chosen ranking scheme gives proper consideration to both weight of evidence and potency.

Because CAG believes that both weight of evidence and potency are essential to describing a carcinogenic hazard, it is interesting to see whether the two concepts are related. An empirical analysis of the CERCLA potential carcinogens shows that there is no striking relationship between weight of evidence and potency. Table 2 is a cross-tabulation of substances by weight of evidence and potency. It excludes substances where the dose-response data are not suitable for assigning a potency group and a mid-range potency is assigned, or where the potency group is based on a related compound.

 Table 2

 Count of Substances by Weight of Evidence and Potency

		Potency group			
		1	2	3	Total
	A	5	3	2	10
Weight-of-	B1	2	4	0	6
group	B2	23	50	16	89
	С	1	5	5	11
	Total	31	62	23	116

There are good reasons not to expect a correlation. A high potency means that relatively small doses of a substance cause cancer. A high weight of evidence means that there is a good epidemiologic study making a credible case that a substance causes cancer. These are not the same. The existence of good epidemiologic studies depends on many factors, among them the availability of a study population that can be followed over a sufficiently long time, the absence of confounding factors that prevent a substance from being isolated as a cause of cancer and the interest and funding of investigators. This lack of correlation reinforces CAG's position that weight of evidence and potency are two independent pieces of information that describe a carcinogenic hazard.

After CAG has completed the hazard rankings, OSWER translates the hazard rankings of High, Medium and Low into RQs of 1, 10 and 100 lbs. OSWER then compares these RQs with the RQs for the other primary criteria and evaluates the degradative processes before adjusting the statutory RQs in a rulemaking.

CONCLUSIONS

The U.S. EPA is now about to adjust the statutory reportable quantities of most potential carcinogens. To support this effort, the U.S. EPA's Carcinogen Assessment Group has developed a methodology for ranking potential carcinogens. This methodology is based on two factors—weight of evidence and potency that the Carcinogen Assessment Group considers essential to describing a carcinogenic hazard.

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Quantitative Risk Assessment as the Basis For Definition of Extent of Remedial Action At the Leetown Pesticide Superfund Site

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ABSTRACT

A study of comparative public health risk was undertaken by the U.S. EPA in conjunction with a Remedial Investigation of the Leetown Pesticide Superfund Site. The 2½ mile² area encompassing the site includes a watershed tributary to the Potomac River and is approximately 5 miles west of Harper's Ferry, West Virginia.

Hazardous waste activity at the Leetown site included both land disposal of pesticides and accumulation of pesticide residues in soils of former orchards within the study area. In defining source areas within the watershed to be considered candidates for remedial action, the U.S. EPA used quantitative risk evaluation, comparative levels of residual contamination and the character of the hazardous waste activity (i.e., disposal versus agricultural application).

By thoroughly characterizing a total of six suspected pesticide source areas, the U.S. EPA was able to focus remedial action on an area of land disposal and two areas where concentrated residual pesticide levels had occurred as a result of improper storage and careless handling of pesticides during mixing operations. In so doing, the U.S. EPA avoided establishing the precedent at this site of using Superfund monies to remediate residual contamination resulting solely from agrichemical application.

This paper presents the basis for characterization of the source areas and the rationale employed by the U.S. EPA in establishing the scope and extent of remedial actions required at the Leetown Pesticide Site.

INTRODUCTION

An evaluation of comparative public health risk posed primarily by the presence of residual pesticide levels in soils at the Leetown Pesticide Superfund Site was performed in conjunction with a Remedial Investigation (RI) of the site. In addition to quantifying risk, the evaluation played an important role in the definition of candidate source areas to be remediated and in the establishment of target levels for remedial action. Reliance upon the risk evaluation, at least in part, was especially useful at the Leetown Pesticide Site since the pesticide residual in soil resulted not only from unauthorized land disposal, but also from typical use of pesticides in insect control on orchards within the study area in the 1940s and 1950s.

Risk assessments estimate the magnitude and probability of harm to public health or the environment as a result of the release of a hazardous substance. In the present case, probable contamination migration pathways were first characterized to serve as a basis for definition of a comprehensive, basin-wide environmental sampling program. The chemical analytical results obtained served as input to accepted models of environmental fate and transport phenomena, resulting in calculation of anticipated doses at receptors. The anticipated health risk was then calculated based on assumptions regarding the probability of exposure via various routes (e.g., dermal contact, inhalation of particulates). By basing the risk assessment on actual empirical data and extrapolating from the data base where necessary to approximate future contaminant distribution, it was possible to define baseline risks which will remain operable unless mitigated by remedial action.

After evaluating environmental and public health risks, riskbased goals for cleanup technologies were proposed. The residual risks associated with each remedial alternative were then contrasted to those presented under the baseline or "no action" alternative.



Figure 1 General Site Location

DESCRIPTION OF THE LEETOWN PESTICIDE SITE

The Leetown Pesticide Site is located in northeastern West Virginia, about 5 miles west of Harper's Ferry in Jefferson County.¹ Fig. 1 is a general site location map while Fig. 2 provides a plan of the study area, showing the six areas of suspected pesticide disposal identified during the RI (see below).

- Former Pesticide Pile Area
- Former Jefferson Orchard
- Former Jefferson Orchard Pesticide Mixing Area
- Former Crimm Orchard
- Former Crimm Orchard Packing Shed
- Suspected Pesticide Landfarm



- () FORMER PESTICIDE PILE AREA
- 2 FORMER JEFFERSON ORCHARD
- (3) FORMER JEFFERSON ORCHARD PESTICIDE MIXING AREA
- FORMER CRIMM ORCHARD
- 5 FORMER CRIMM ORCHARD PACKING SHED
- 6 SUSPECTED PESTICIDE LANDFARM

Figure 2 Plan of the Study Area

The areas of suspected pesticide contamination lie predominantly within the Bell Spring Run watershed. This watershed drains to Hopewell Run and, ultimately, to the Potomac River.

The site was first brought to the attention of the West Virginia Department of Environmental Resources (WVDNR) in 1981. Initial concern was raised by personnel from the Leetown National Fisheries Center (NFC) over the apparent dumping of pesticidecontamianted debris in the upper reaches of the watershed. The NFC is a prominent U.S. Fish & Wildlife Service (USF&WS) research facility located at the base of the Bell Spring Run watershed; it specializes in research on infectious fish diseases. In addition to the NFC, the surrounding agricultural community of Leetown utilizes groundwater from the watershed as its sole source of potable water.

The area of initial concern relative to pesticide dumping has been noted in Fig. 2 as the Pesticide Pile Area. At the time of discovery, it was alleged that this area and a nearby tract of about 50 acres (Suspected Pesticide Landfarm) were repositories for pesticide-contaminated debris from a fire at a local agrichemical warehouse. The "pile" was physically removed in 1983 under direction of the U.S. EPA and the WVDNR; however, sampling performed during the RI indicated that substantial pesticide contamination still remains at this site. Sampling during the RI did not provide evidence of similar pesticide disposal at the Suspected Pesticide Landfarm. Rather, pesticide residuals in the soils of the landfarm area were consistent with its use for corn production.

The remaining areas of pesticide contamination were associated with past use of much of the watershed as an orchard. The Jefferson Orchard formerly occupied approximately 170 acres and was an active orchard during the 1940s and 1950s. A 25-acre tract east of Route 15/1 subsequently was sold to the Robinson family. The remainder ultimately was purchased by the USF&WS. The "Robinson Property" apparently was the focus of the orchard operations and was the most intensively-used portion of the Jefferson Orchard. A fourth area of pesticide contamination is located at the southwestern periphery of the Robinson Property. This location has been shown on Fig. 2 as the Jefferson Orchard Pesticide Mixing Area. It was apparently a customary practice in the local area for orchard pesticides to be mixed at points where roads crossed streams, primarily due to the easy access to water both to formulate the sprays and to rinse out the spray equipment.

A second abandoned orchard, the Crimm Orchard, was located across Bell Spring Run southwest of the Jefferson Orchard. A former orchard packing shed presently stands in the approximate middle of the former Crimm Orchard. In addition to serving as a packing shed, the eastern portion of this land was used for pesticide formulation and storage.

Presently, there is little evidence of the existence of the orchards other than the pesticide mixing areas and the elevated residual pesticide levels in the soils. These areas now are being used for production of silage or corn grain as cattle feed and/or for pasturing dairy cattle.

RISK ASSESSMENT BASIS FOR AREAS REQUIRING REMEDIAL ACTION

Requirement for Definition of Source Areas Candidate for Remedial Action

As discussed, the study area included several potential sources of pesticides. However, the more extensive areas of residual soil contamination (i.e., the orchards) are "typical" of much of Jefferson County, since much of the land at one time supported orchards. In addition, this contamination did not result from "disposal" activities normally associated with uncontrolled hazardous waste sites. These factors emphasized the importance of establishing a sound basis for definition of those areas candidate for remedial action. This basis was grounded in the following:

- Comparison of contaminant levels within the study area as well as with average agricultural levels reported in the literature
- Comparative risk assessment

The quantitative risk assessment formed a cornerstone in this development and is discussed in detail in this section. Insight into the actual decision-making processes employed by the U.S. EPA in selecting the scope and extent of remedial action are discussed in the following section.

Comparative levels of risk, particularly to human receptors, were used to focus the study on actual areas of concern at the Leetown Pesticide Site. The six source areas identified in the RI were reduced to the three areas noted below that present the most significant risk in excess of that considered acceptable by the U.S. EPA's decision-making process.

- Former Pesticide Pile Area
- Former Jefferson Orchard Pesticide Mixing Area
- Former Crimm Orchard Packing Shed

Atypically high areas of soil contamination were identified by comparing source area contaminant levels and those normally found in U.S. orchards or cornfields. Table 1 presents a comparison of site contaminant levels with literature values for residual pesticide contamination in agricultural areas.

Table 1 Mean Pesticide Residue Concentrations in U.S. Soils' Values Reported in ppb (µg/kg)

Pesticide	US Orchards	Abandoned Orchards (Leetown)	US <u>Cornfields</u>	Suspected Pesticide Landfarm (Leetown)
DDT	3,310-122,600	9,186	100-4,050	18
toxaphene	7,720	ŇD	NR	373
aldrin	20	ND	10	0.6
dieldrin	190-1.410	ND	90	15
heptachlor	NR	ND	4	0.9

Note:

ND = Not Detected

Although DDT and its metabolites—DDD and DDE—were the most pervasive and concentrated contaminants, the potential impact of all of the detected pesticides was evaluated.

The three source areas noted above contained levels of DDT that could be considered excessive. The pesticide pile soils contained up to 476,000 ppb of DDT and its metabolites, while the other two areas exhibited contamination levels between 22,000 and 96,000 ppb of these species. The orchards and the suspected landfarm contained much lower levels of pesticides.

Levels of arsenic in the pesticide pile area (21 to 759 ppm) and in the pesticide mixing area (23 to 110 ppm) exceeded the average arsenic concentrations expected in orchard areas (110 ppm)³ and in non-agricultural areas (7.4 ppm).³ The average lead concentration in soil is approximately 17 ppm; levels in the pesticide pile reached 1,040 ppm, levels in the pesticide mixing area reached 328 ppm and levels in the soils near the packing shed reached as high as 725 ppm.

Arsenic's potential carcinogenicity is the center of current debate. It has been assigned a carcinogenic potency index by the U.S. EPA Carcinogen Assessment Group (CAG). At the same time, however, there is an acceptable level for arsenic in drinking water (50 μ g/l). If the potency index were used to calculate the risk from ingestion of water containing 50 μ g/l of arsenic, it would result in an incremental cancer risk of 1 in 50 (i.c., one additional case of cancer in an exposed population of 50 persons). Definition of an "acceptable" level of a carcinogen in drinking water is somewhat contradictory, since carcinogens are, by definition, "non-threshold" chemicals (i.e., the occurrence of cancer is not related to dosage). In any case, arsenic is thought to cause only skin cancer by the oral and inhalational routes of exposure and is not known to be dermally-absorbed in any form.*

Exposure Assessment

The site assessment process included a systematic evaluation of potential or actual contaminant migration pathways, exposure routes and populations at risk. Each of the potential source areas was examined in light of public health and environmental risk.

Contaminant Migration Pathways

and Exposure Routes

Contamination in the pesticide pile area is confined to the surface soils and will be released only when the soil is disturbed. The most likely release mechanisms are erosion of soils by surface water runoff or wind. Runoff could eventually carry contaminants to Bell Spring Run where they might accumulate and magnify in the aquatic food chain. The carnivores at the highest trophic level in the stream are creek chubs (Semotilus atromaculatus) and fallfish (S. corporalis), which are not considered gamefish. Thus, human exposure as a result of eating fish from Bell Spring Run is unlikely. Fugitive dust from this area could be carried off-site, exposing nearby residents.

Particulates could be emitted during tilling. Although the area is currently in pasture, land use may change. Farmers could experience both dermal and inhalational exposures to pesticideladen particulates.

Soil disturbance is also the primary release mechanism for DDT-contaminated soils in the mixing area and near the packing shed. Both areas presently are well-vegetated, however, effectively minimizing air and water erosion. The proximity of the pesticide mixing area to Bell Spring Run may result in direct deposition of contaminated soils in the stream during intense storms. As with the pesticide pile area, this area could be tilled, thereby exposing farmers to soil contaminants.

Activities in the former orchard areas and the suspected landfarm area have some associated risks. Part of the former Jefferson Orchard presently is used for production of silage corn, leading to an evaluation of the risk associated with ingestion of milk from a local dairy. The orchards and the landfarm could add contaminated sediments to nearby streams. In addition, tilling these areas could result in a human exposure to contaminants.

Exposure Coefficients and

Carcinogenic Risk Estimation

Once contaminant migration pathways and exposure routes are defined, doses can be estimated and risks can be quantified. Doses are determined by the amount of a contaminant that comes in contact with a receptor's skin, lungs or gastrointestinal tract, adjusting for bodily absorption. Conservative guidance on absorption is to use 100% unless another rate has been reported. A dose in mg/day can be converted to a body dose by dividing the dose by a representative body weight in kilograms (kg), thus producing a dose in mg/kg/day. The following calculation is provided by way of example. Assuming:

- Residual pesticide concentration in soil of 0.5 mg/kg
- Ingestion of 1 mg/day during plowing
- Exposure rate of 10 days/yr for 40 yr
- An average lifetime of 70 (25,550 days)
- An average adult body weight of 70 kg
- Absorption rate of 100%

a dose can be calculated as follows:

$$\frac{(0.5 \text{ mg})(1 \times 10^{-6} \text{ kg})(10 \text{ days})(40 \text{ yr})(1.0)}{\frac{\text{kg}}{\text{cm}}} = 1.1 \times 10^{-10} \text{ mg/kg-day}}$$
(70 kg) (25,550 days)

*/*1\

NR = Not Reported

 Table 2

 Exposure Coefficients Used at the Leetown Site

Exposure Route	Age (Yr)	Body Weight (Kg)	Exposed Surface Area (cm2)	Bioaccumulation Factor	Estimated Exposure Duration	Absorption Factor
Inhalation - Tilling	70	70	NA	NA	10 day, 12 hr/day for 40 yr	0.75 (7)
Inhalation - Fugitive Dust	70	70	NA	NA	25 day/mo, 10 mo/yr for 70 yr	0.75 (7)
Dermal Contact	70	70	2948(7)	NA	120 day/yr for 40 yr	0.10 (8)
Ingestion of Milk	70	70	NA	0.7 (7)	70 yr	1.0 (8)

Note: NA = Not Applicable

 Table 3

 Inhalational Carcinogenic Risks from Tilling the Soil

Contaminant	Pesticide Pile	Pesticide Mixing Area	Packing Shed	Jefferson Orchard	Crimm Orchard	Suspected Landfarm
DDT/metabolites	4.4 x 10 ⁻⁴	4.3 x 10 ⁻⁴	5.7 x 10 ⁻⁵	8.2 × 10 ⁻⁵	2.9 x 10 ⁻⁵	1.5×10^{-5}
alpha-BHC	1.5 x 10 ⁻⁴	ND	ND	ND	ND	1.1×10^{-6}
beta-BHC	3.5 x 10 ⁻⁷	ND	ND	ND	ND	4.6 × 10 ⁻⁸
gamma – BHC	5.4 x 10 ⁻⁷	ND	ND	ND	ND	1.6×10^{-8}
toxaphene	ND	ND	ND	ND	ND	5.7×10^{-6}
chlordane	ND	ND	ND	ND	ND	3.1×10^{-7}
aldrin	ND	ND	ND	ND	ND	2.2×10^{-9}
dieldrin	ND	ND	ND	ND	ND	1.5×10^{-7}
arsenic	5.0 × 10-2	1.7 x 10-2	4.4×10^{-3}	ND	ND	$2.8 \times 10^{-3} *$
TOTAL RISK	5.1 x 10-2 (1 in 20)	1.7 x 10-2 (1 in 60)	4.5×10^{-3} (1 in 225)	8.2 x 10 ⁻⁵ (1 1n 12,000)	2.9 x 10 ⁻⁵ (1 in 34,500)	2.8×10^{-3} (1 in 360)

Notes:

ND = Not Detected during laboratory analysis

* = Due to arsenic at high concentration in one sample

This dose results in a dimensionless risk value when multiplied by the carcinogenic potency factor, which has the units of kgday/mg. The potency factor converts a dose directly to risk using a linear dose-response curve recommended for use by the U.S. EPA.⁵ The "linearized multi-stage" model is used as a conservative, upper-limit estimate of risk; that is, the true risk is not likely to be higher than the estimate, but it could be considerably lower. In this study, a worst-case estimate was presented, tempered by reasonable exposure durations. However, risk estimates so derived are very sensitive to the assumed factors in the dose estimation calculations.

The probable incidence of adverse (carcinogenic) health effects was estimated using the exposure scenarios presented in Table 2. A total risk, according to U.S. EPA guidance for exposure to multiple compounds, is the sum of the individual risks.⁶ This additive model assumes that individual intakes are small, that there are no antagonistic or synergistic effects between chemicals and that all the chemicals produce the same health effect (in this case, cancer). Cancer risks from various exposure routes also are additive if the exposed populations are the same.

Total dermal risks to farmers calculated for all existing or potential agricultural areas ranged from 6.6×10^{-7} (1/1,520,000) at the suspected pesticide landfarm to 5×10^{-5} (1/18,000) at the pesticide pile. Maximum and average risks were

calculated using the maximum and average contaminant concentrations, but the average risk is more representative of the exposures incurred in tilling a large area. These dermal risk calculations do not include arsenic because arsenic is not dermally absorbed.

Table 3 is a typical risk summary chart, presenting the average inhalational risks associated with tilling contaminated soils. Inhalational risks were somewhat higher than those associated with dermal contact and served as the basis for development of the target cleanup levels.

Fugitive dust blown from the plowed fields was a third potential route of human exposure. Risks are generally much lower than those for inhalation during tilling, except where arsenic is present. Estimated risks ranged from 1.2×10^{-10} (1/8,200,000,000) at the packing shed to 1.3×10^{-6} (1/770,000) at the suspected pesticide landfarm, chiefly due to the greater number of different types of pesticides found at the latter.

If lifetime milk consumption was from cattle grazing within the watershed and feeding on silage and corn grain grown within the study area, the additional risk of cancer would be approximately 1.3×10^{-4} (1/7,800). However, in actual practice, milk produced within the Bell Spring Run watershed is mixed with that from other dairies at the local cooperative. Based on lifetime milk consumption from the cooperative, the estimated risk is reduced

to 9.9 \times 10⁻⁸ (1/10,000,000).

Establishment of Target Cleanup Levels

The risk assessment was used to develop target cleanup levels for an engineering feasibility study of potential remedial alternatives using the same exposure scenarios and risk calculation equations as described earlier, but solving for a soil concentration by using a given risk goal such as 1×10^{-6} or 1×10^{-4} . For example, if Risk = (potency factor)(contaminant concentration) (exposure coefficient), then contaminant concentration =

<u>Risk</u> (2)

(potency factor)(exposure coefficient)

The resultant reduction in pesticide concentrations must be attained during remediation. For every order of magnitude change in desired risk, the soil concentration also will change by an order of magnitude. This allows the U.S. EPA to set conservative action levels to meet any desired residual risk. As an example, in order to achieve a 1×10^{-6} incremental cancer risk at the three areas subject to remedial action, pesticide levels would have to be reduced to the following levels:

Contaminant	Pesticide Pile Area	Pesticide Mixing Area	Packing Shed
DDT/metabolites	300	1,200	1,200
alpha-BHC	10		
beta-BHC	60		
gamma-BHC	80		

Note: All values in µg/kg

---indicates that these contaminants were not found at these areas at concentrations requiring the establishment of action levels

Where more than one carcinogen is present in the soil matrix, proposed residual soil concentrations for each contaminant must be proportionally lowered. That is, if four carcinogens are present in the soil and the desired residual risk is 1×10^{-6} , then the concentration of each contaminant must correspond to a risk of

$$\frac{1 \times 10^{-6}}{4}$$

or 2.5 \times 10⁻⁷. This method assumes that the effects of all the contaminants are equally harmful.

The only contaminant action level at this site that was not entirely based on risk is that for arsenic. When risks were calculated for inhalation of arsenic, it was found that a concentration of 7 to 10 mg/kg resulted in a risk of about 3×10^{-3} . However, such levels of arsenic can be considered normal for soils in the eastern United States. Therefore, the target cleanup level for arsenic was set at approximately 10 mg/kg, which is a reasonable background level. It is not technologically feasible to remove arsenic to levels that are below those found naturally.

DEVELOPMENT OF REMEDIAL ACTION ALTERNATIVES

When developing alternatives to address a problem such as the one at Leetown, or any other hazardous waste site, it is always advantageous to remember the objectives of the remedial action. These objectives can be and should be discussed and agreed upon long before the final data are received or before the feasibility study begins to take shape. For Leetown, the remedial action objectives were developed in the final Leetown Pesticide Site Work Plan' some 15 months before the selection of the remedial action alternative. The objectives which molded the appropriate responses to the contamination at Leetown called for:

"... the determination of the remedial measures necessary to mitigate the existing and potential impacts of contaminant migration on air, groundwater, surface water, biota and soil resources in the vicinity of the site."

Based on these objectives and coupled with the information and data from the remedial investigation, eight remedial action alternatives were developed for the Leetown site:

- No action
- No action with monitoring
- Consolidation with soil cover
- Consolidation with multimedia cap
- On-site landfill
- Off-site disposal
- Off-site disposal with incineration
- On-site treatment/off-site disposal

Each alternative would achieve the objectives as stated above (except the no action alternatives which are required as a baseline comparison) and would provide for the mitigation of potential contaminant migration through the air and to the surface waters in the affected area. With all of the environmental and health objectives addressed, the selection of the remedial alternative is reduced to consideration of other factors such as costs, implementability, institutional constraints and public opinion.

Issues in the Evaluation of the Remedial Action Alternatives

A discussion of the major issues unique to this site that influenced the selection of the final remedy at Leetown is provided below.

Background Contamination

To better define the extent of the remedial action at Lectown, the U.S. EPA had to establish a site-specific definition for "background contamination" and from there determine which areas fit that definition. For this site it was determined that contamination in the soil due to the normal application of pesticides on the orchard areas would be considered as background, while contamination in areas of careless pesticide application (e.g., the pesticide mixing area) and the dumping of contaminated material not connected with the orchard operation (i.e., the former pesticide pile area) would be considered the contaminated areas.

Acceptable Risks

By establishing background contaminant levels at this site, the U.S. EPA did not *ipso facto* determine that any areas considered as background were not to be considered in the final remedy. The quantitative risk analysis for defined "background" areas had to be reviewed and the concept of acceptable risk had to be discussed.

For example, by not taking any action in the former orchard areas, the average inhalational carcinogenic risks (excluding arsenic) for the exposure scenario as discussed earlier for the former Jefferson and Crimm Orchards are 8.2×10^{-5} and 2.9×10^{-5} , respectively. The U.S. EPA has determined in this case that these risks, which were calculated from a very conservative exposure scenario, were acceptable.

The decision to call these risks acceptable was considerably influenced by institutional factors and the consequences of the potential precedent-setting decision that would have addressed historical contamination due to normal application of pesticides as hazardous waste activity subject to remediation. A decision by the U.S. EPA to remediate the orchard areas would have set the precedent of using Superfund monies to remedy a problem which may well be very common in agricultural locations throughout the United States. If the U.S. EPA had determined the extent of remedial action based solely on the exposure scenario risk calculations, it then would seem that almost all former orchard areas and other agricultural use areas in this country would be candidates for inclusion on the National Priorities List and eligible for Superfund cleanup.

This does not, in turn, establish the policy that any orchard or agricultural area with similar pesticide concentrations would not pose an unacceptable risk to potential targets. The potential exposure scenario (chronic inhalation of dust from tilling) and the likelihood of that scenario actually occurring had some influence in determining acceptable risk. These decisions have to be made on a site-specific basis.

Arsenic and Lead Contamination

The early orchard operators used lead arsenate as the pesticide of choice, resulting in the occurrence of these two metals in the soil. Table 4 shows that the arsenic and lead levels found in the Robinson Property (non-disposal) areas are similar to those levels found in the pesticide pile area and the mixing area. However,

 Table 4

 Arsenic and Lead Levels in Leetown Pesticide Study

 (concentrations in $\mu g/kg$)

Location	As. Range	Average Concentration	Detection Frequency	*Adjusted Average
Orchard background (USF&W Areas)	10-53	38	חו	41
Orchard background (Robinson Property Area)	111-123	115	2/2	116
Hixing Area	23-110	62	3/3	62
Pesticide Pile Area	21-759	137	15/15	98

Location	Pb Range	Average <u>Concentration</u>	Detection Frequency	Adjusted Average
Orchard background (USF&W Areas)	36-341	209	חו	217
Orchard background (Robinson Property Area)	474-991	732	2/2	7 32
Hixing Area	104-328	199	3/3	199
Pesticide Pile Area	44-1,040	304	15/15	267

^{*}Adjusted average obtained by eliminating the high and low sample concentration where significant number of samples allow.

the average concentration of arsenic and lead found in the orchards that are now the USF&WS properties are somewhat lower. This decrease is explained by the age of the orchard areas. The orchard that once occupied the Robinson Property area was the older and more extensively used portion of the Jefferson Orchard. Therefore, the accumulation of lead arsenate is greater in this area. However, the comparative risks associated with these concentrations of arsenic and lead are within the same order of magnitude across the study area. This exposure is unlike the risks from DDT and its metabolites which were an order of magnitude higher at the Robinson Property disposal areas than in the orchard background areas.

Therefore, it can be concluded that the levels of arsenic and lead derived from historical lead arsenate spraying from agricultural activities are somewhat consistent over the orchard areas. On the other hand, the contrast of DDT levels and risks between the disposal areas and the orchard background areas indicates that the elevated levels of pesticides and other contaminants in the disposal areas were caused by non-agricultural activities. In the pesticide pile area, the cause was dumping, while in the pesticide mixing areas (including the packing shed) the cause seems to be carelessly handling the pesticides. To conclude, the same factors which eliminate the orchard areas from remedial action (acceptable risks, exposure scenario, historical contamination) also eliminate the need to remediate the lead and arsenic contamination in the Leetown area.

Innocent Landowner Issue

Of particular interest in this investigation was another factor which was discussed in the decision-making process—that of the innocent landowner. As presently configured, all of the remedial actions would take place on the Robinson Property where the bulk of the contamination lies. A landowner is statutorily a responsible party. However, in the present case, the Robinsons may be considered victims of a "midnight dumping" episode in which the land lessor dumped in the area which is now the former pesticide pile location.

Selection of any alternative which incorporated on-site storage of the contaminated soils would negatively impact future use (and value) of the property. The off-site disposal alternatives and the on-site treatment options would only require a short-term (2 years maximum for on-site treatment) reservation of land. Again, it is stressed that this is only a small variable in the overall decisionmaking process of selecting the final remedial alternative.

Selection of the Remedial Action Alternative

The remedy selected to address the pesticide contamination at the mixing area locations and the former pesticide pile area in Leetown was the on-site treatment option. This alternative would be designed to eliminate DDT and other pesticide contamination by microbial degradation.

Destruction of this waste on-site is a desirable alternative since it eliminates potential exposure to DDT and its metabolites from future tilling operations in the area. In addition, this option requires only a temporary dedication of lands in the site vicinity for treatment of wastes. Waste transport from the source areas over public roads is limited, and no hazardous waste disposal capacity at an off-site RCRA-approved facility is necessary. The key provision in the selection of this remedy is the destruction of the wastes. This "treatment" of hazardous contamination is consistent with recent U.S. EPA policy and guidance on selecting an environmental remedy at a Superfund site. The U.S. EPA's Off-site Disposal Policy¹⁰ states:

> "It is EPA's policy to pursue response actions that use treatment, reuse or recycling, over land disposal to the greatest extent practicable . . . and when recommending and selecting the appropriate remedial action, treatment reuse or recycling may be found more protective of public health and the environment than land disposal."

In addition, recent interim guidance from the U.S. EPA encourages the consideration of treatment technologies and gives guidance on how to approach the issue of cost-effectiveness of treatment operations over a long-term period.

Finally, the preamble to the National Contingency Plan states that higher-cost alternative technologies can be selected when treatment or destruction offers a permanent solution to environmental contamination.

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Innovative Use of Toxicological Data to Improve Cost-Effectiveness of Waste Cleanup

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ABSTRACT

A new approach for estimating the total cancer risk associated with given exposures to multiple polynuclear aromatic hydrocarbons (PAHs) has been developed. This approach is based upon two important methodological improvements. First, a mathematical dose-response model that incorporates the most advanced understanding of the carcinogenic mechanisms of action of PAHs was generated for benzo[a]pyrene (B[a]P). The parameters in this model were estimated for both ingestion and inhalation of B[a]P. Second, the open literature was surveyed for data from carcinogenesis bioassays in which B[a]P and other PAHs were tested simultaneously in the same test system. Based on the assumption that the functional form of the theoretical dose-response model for B[a]P is applicable to the other PAHs, relative potency estimates were obtained from each of the relevant studies.

A dose-response model for joint exposure to multiple PAHs was generated, using the relative potency estimates and the B[a]P theoretical model functional form. An example of the total risk associated with exposure to multiple PAHs was given to illustrate how cancer potency estimates can be modified to obtain a more cost-effective remedial solution. Also discussed are the conditions under which the U.S. EPA and other Federal and state regulatory agencies would be likely to accept this approach to improving cost-effectiveness of waste cleanup.

INTRODUCTION

Most regulatory decisions have specified that the total risk to an individual exposed to carcinogens at a Superfund site must be controlled to fall within a target range of 1×10^{-4} to 1×10^{-7} . This goal is to be achieved through the development of remedial actions that reduce uncontrolled exposures to levels that lie within the target risk range.

Designing cost-effective remedial measures to reduce exposure to multiple potential carcinogens is a complex legal, engineering and toxicological problem. Virtually all proposed remedial solutions treat the carcinogen potency factors as rigid physical constants. A far more cost-effective approach often may be achieved by incorporating improvements in the toxicological data base and/ or carcinogenic dose-response models into the remedial solution.

Such an approach is consistent with the U.S. EPA policy of updating the cancer potency numbers whenever there is sufficient scientific evidence that changes would improve the estimate. At present, a number of the models used to estimate the cancer potency factors used in Superfund public health evaluations do not make best use of available information. Time and/or resource constraints imposed in the development of the cancer potency value and subsequent expansion of the knowledge base are the prime reasons for the sometimes inadequate cancer potency estimates presently in use.

B[a]P traditionally has been used by the U.S. EPA as the indicator of the carcinogenicity for those PAHs suspected of being carcinogens. Many states have followed suit. However, it is known that B[a]P is one of the most potent carcinogens of the polycyclic organic family. It may, in fact, be as many as three orders of magnitude more potent than some of the other suspected PAH carcinogens. It is therefore possible to hypothesize that, if mathematical models based upon relative potency estimates of PAHs compared to B[a]P were developed to estimate the joint risk of the total exposure, carcinogenicity estimates might be reduced considerably.

This approach has been used successfully in the past. A relative potency approach for estimating risk associated with PAHs in diesel exhaust has been obtained. This approach avoids the over-estimation of risk by the use of B[a]P as a surrogate for these PAHs.¹ A National Academy of Science oversight committee developed the approach, and it has been accepted by the U.S. EPA as the most appropriate for characterizing the potency of PAH mixtures from diesel emissions. In addition, long-term inhalation bioassays are now being completed at the Lovelace Laboratories, and the results support the comparative potency approach developed earlier. We believe that a similar approach for estimating joint PAH risk from other sources is a highly credible alternative to the current system.

In this paper, new state-of-the-art dose-response models are derived for B[a]P for both ingestion and inhalation exposures. Values for the relative potency of various PAHs compared to B[a]P are estimated using the new dose-response model and appropriate carcinogenicity studies from the literature. By combining this information, a dose-response model for joint exposures to PAHs is generated. Finally, we discuss the factors that would increase the probability of acceptance of this and other innovative approaches by the regulatory agencies, and we offer arguments for the cost-effectiveness of such approaches.

DEVELOPMENT OF A MATHEMATICAL CANCER RISK MODEL

Advances in the estimation of the cancer risk associated with exposure fo B[a]P within the framework of the available data base are dependent upon improvements in dose-response modeling. In this report, new approaches to cancer risk modeling are reviewed, and a general model is recommended. A special case of this general model is developed based on the postulated mechanism of action of B[a]P, and the information that is consistent with this hypothesis is noted. Finally, the postulated model is fitted to the available cancer dose-response data on the effects of ingesting or inhaling B[a]P.

Multistage Models

Multistage and related mathematical models of carcinogenesis have evolved over the past 30 years. Comprehensive reviews of the development of these models through the late 1970s are found in articles by Whittemore² and Whittemore and Keller.³ In recent years, advances in the understanding of the mechanisms of carcinogenesis have been incorporated into more realistic variations of multistage mathematical models. Notable in this regard is the two-stage model that takes into account the proliferation of initiated, first-stage cells. This model is discussed in detail in Moolgavkar and Venzon,⁴ Moolgavkar and Knudson,³ and Moolgavkar.⁶ Thorslund *et al.*⁷ have extended the two-stage model to incorporate the effects of environmental agents on cell transition rates, first-stage cell proliferation rates and cell death rates. In its general form, the model may be written as:

$$P(x,t) = 1 - exp - M[1 + (1 + S)x](1 + Sx)(exp[G(x)t]) - 1 - G(x)t)/G(x)2$$
(1)

where:

S	is the smallest relative transition rate,
S + 1	is the largest relative transition rate,
Μ	is a scaling factor,
x	is a constant lifetime exposure of the reactive
	form of the agent at the molecular or cellular site
	of action,
t	is the age at which the risk is evaluated, and
G(x)	is the exposure-dependent growth rate of the
	first-stage, i.e., preneoplastic cells.

In the next section, the rationale for using a specific form of this model for B[a]P is explained.

Dose-Response Model for B[a]P

One simple form of the B[a]P dose-response model is based on two assumptions: (1) that both transition rates are the same linear function of dose x, (2) and that the growth rate of preneoplastic cells is independent of the exposure level. As Moolgavkar⁴ pointed out, such a situation would occur when two genes on homologous chromosomes that regulate cell growth experience critical point mutations, which would reduce the controls on growth. If these point mutations are linear functions of dose, the dose-response relationship may be expressed as:

$$P(x,t) = 1 - exp - M(1 + Sx)^{2}[exp(Gt) - I - Gt]/G^{2}$$
(2)

which reduces to the form:

$$P(x) = 1 - \exp[-A(1 + Sx)^2]$$
(3)

if the time of observation is assumed to be constant across all exposure groups.

This model, in its various forms, has a number of advantages. Among the most important are the following:

- At low doses, the models converge to a linear, no-threshold form;
- It can be used to adjust for different lengths of observation among exposure groups;
- The time-independent form of the model has only two parameters that have to be estimated, so that goodness-of-fit tests can be run on the data from the standard bioassay with one control and two exposure groups;
- A stable point estimate of risk can be obtained directly;
- The mathematical form of the model follows directly from the most widely accepted hypothesis of the mechanisms of cancer induction.

Rationale for Using the Model: Mechanism of Tumorigenesis for Benzola)pyrene

B[a]P is metabolized by the cytochrome P450 microsomal

mixed-function oxidase system to a number of hydroxylated derivatives that are generally conjugated as glucuronide, sulfate or mercapturic acid compounds. Sims *et al.*^a noted that the intrinsically active form of B[a]P responsible for its covalent binding to DNA is the 7,8-diol-9,10-epoxide; it is generally accepted that this metabolite is responsible for the tumorigenicity of B[a]P (IARC 1983). Covalent binding of reactive metabolites of B[a]P and other carcinogenic PAHs to DNA appears to be an essential step in the production of PAH-induced neoplasia.^{9,10} If the adducts are not repaired, replication of damaged DNA during cell proliferation may lead to mutation. The induction of neoplasis thus is related both to the extent to which PAHs bind to DNA and to the level of cell proliferation in the target tissue.

Pereira et al.¹¹ applied single doses of B[a]P topically to ICR/ Ha mice and found a linear relationship between the applied dose and the amount of each of the two major B[a]P-DNA adducts formed in the epidermis over a dose range of 0.01 to 300 mg of B[a]P/mouse. The level of adduct reached a maximum after 7 hr and remained constant for the next 49 hr, indicating that repair of such lesions is slow.

Adriaenssens et al.¹² administered single doses of B[a]P orally via intubation to rats and examined the formation of DNA adducts over a dose range of 2 to 1,351 umol/kg (0.048 to 29.7 umol/mouse). The rate of formation of the major diol epoxide-DNA adduct was linear with respect to dose in the forestomach. Although the authors state their results show no linear relationship between dose and adduct formation in the lung, we contend the extent of the deviation from linearity is so slight that such a relationship may indeed have existed.

B[a]P metabolites bind to DNA in every tissue that has been examined, regardless of species, dose or route of administration. Adducts tend to be persistent and are similar both qualitatively and quantitatively in various tissues, whether or not the tissue is a target for cancer.¹³ Thus, formation of an adduct to DNA is a necessary step in B[a]P-induced carcinogenesis, but other factors also may be involved. If target tissues have higher rates of cell proliferation than other tissues, it may be postulated that these tissues have a greater probability of fixing a mutation following adduct formation than tissues with lower rates of proliferation.

In an extensive series of skin-painting studies in mice, it has been shown that the tumor dose-response relationship is quadratic in form,¹⁴ even though the DNA-B[a]P adduct formation in mouse skin is linear at the same levels. This seeming contradiction is exactly what we would predict on the basis of the model suggested here if background tumor and mutation rates were low.

Because the evidence strongly suggests that B[a]P is a genotoxic agent acting at two sites on DNA, the two-stage model with equal transition rates is a useful approach for estimating the cancer risk associated with exposure to B[a]P. In the next two sections, the restricted two-stage model is fitted to dose-response data for exposure to B[a]P via both ingestion and inhalation.

Dose-Response Relationship for Oral Exposure to B[a]P

The carcinogenicity of B[a]P via ingestion was investigated in a series of experiments conducted by Neal and Rigdon¹⁵ and by Rigdon and Neal^{16,17}. The most pronounced dose-response relationship, obtained under reasonably consistent conditions, was observed in the Neal and Rigdon¹⁵ study. The results of this experiment are reproduced in Table I. The type of carcinogenesis induced in this study was either a papilloma or a squamous cell carcinoma in the squamous portion of the stomach.

Neal and Rigdon¹⁵ employed a number of experimental factors that are atypical of the standard bioassay protocol in the 1967 study, including a variable age at first exposure, a duration of ex-

 Table 1

 Gastric Tumors in Mice Fed Benzo[a]pyrene

Age first exposed (days)	Milligrams of B[a]P per gram of food	Number of days fed B[a]P	Age killed (in days)	Number with <u>gastric tumors</u> Number of mice
	0.0		300	0/289
30	0.001	110	140	0/25
30	0.01	110	140	0/24
116	0.02	110	226	1/23
33-67	0.03	110	143-177	0/37
33-101	0.04	110	143-211	1/40
31-71	0.045	110	141-183	4/40
17-22	0.05	107-197	124-219	24/34
20-24	· 0.10	98-122	118-146	19/23
18-20	0.25	70-165	88-185	66/73
49	0.25	1	155	0/10
56	0.25	2	162	1/9
49	0.25	4	155	1/10
62	0.25	5	168	4/9
49	0.25	7	155	3/10
91	0.25	30	198	26/26
74	0.10	7	182	0/10
48	0.10	30	156	12/18
98-180	5.0	1	209-294	17/33

Source: Adapted from Neal and Rigdon¹⁵

posure that only lasted about one-fifth of a lifetime and an observation period that was less than one-third of a lifetime.

Syracuse Research Corporation (SRC), under contract to the U.S. EPA, had only limited resources to devote to developing a unit risk estimate for B[a]P. They therefore decided to use the Neal and Rigdon¹⁵ study, but to restrict the data set to that subgroup of the experimental population that had been exposed continuously throughout the experiment. In fitting the multistage model, no adjustments were made for the variable length of the follow-up period or for the age attained at the end of the observation period. Using the standard U.S. EPA approach discussed in Anderson *et al.*, ¹⁸ SRC discarded all data on animals exposed to 50 ppm B[a]P or more because of "lack of fit" and obtained an upper-bound estimate on the chemical's potency to humans of 11.53 (mg/kg/day)⁻¹

If more detailed data were available on the age at first exposure and on the length of exposure for individual animals rather than data on exposure groups as a whole, a more precise, timeadjusted analysis would be possible. Because such detailed information is lacking, however, the approach taken here is to restrict the analysis to exposure groups that are comparable with respect to age at exposure and number of days exposed. The resulting homogeneous experimental subpopulation, selected from the entire experimental population (Table 1), is presented in Table 2. This is the same subgroup used by Chu and Chen, ¹⁹ two members of the U.S. EPA's Carcinogen Assessment Group (CAG), in a paper presented at the Pacific Rim Risk Conference.

 Table 2

 Data Used to Estimate the Dose-Response Relationship

 Between Ingested B[a]P and Gastric Tumors

Dose (ppm in diet)	Dose (x) (mg/kg/day)	Number of mice with <u>gastric tumors</u> Number Exposed	Expected number of tumors pre- dicted by model
0	0.00	0/289	0.50
1	0.13	0/25	0.05
10	1.30	0/24	0.20
30	3.90	0/37	1.32
40	5.20	1/40	2.25
45	5.85	4/40	2.72

Note: This table contains data on only those groups that are comparable with respect to age when first exposed and number of days exposed. The first three columns are from Neal and Rigdon.¹⁵ The fourth column is based on the two-stage, dose-dependent, time-independent, identical transition rate model:

 $P(x) = 1 - \exp[-0.0017256(1 + 0.922x)^2]$

The two-stage model with identical linear dose-dependent transition rates was fitted to the data in Table 2. The joint maximum likelihood estimates of the parameters are indeterminate, with A \longrightarrow 0 and S $\longrightarrow \infty$. One way around this problem is to obtain a positive estimate for "A" using a different method. Based on a priori biological assumptions, we know that A > 0. This follows from the fact that if one assumes that BIaIP exerts its effects via a direct genotoxic mechanism of action, the background tumor rate is proportional to the square of the mutation rate caused by factors other than B[a]P at the critical gene locus. Because a variety of other factors, such as background levels of PAHs, viruses and solar irradiation, have the potential to induce such mutations, a nonzero background tumor rate estimate is required for biological consistency. Unfortunately, the "maximum likelihood" estimate of the background tumor rate is zero, (i.e., 0/289 = 0). We have chosen to use a Bayesian estimator with an invariant prior. This approach has been suggested by Jeffreys²⁰ and by Gart,²¹ among others, in comparable situations where it is known a priori that a zero estimate is unlikely.

Using this approach, the background tumor rate is estimated to be:

$$P(0) = 0.5/(n + 1) = 0.5/290 = 0.0017241$$
(4)

Equating this value to the parametric form of the two-stage, dosedependent, identical transition rate model yields the following relationship:

$$P(0) = 0.0017241 = 1 - \exp[-A(1 + S \cdot 0)^2] = 1 - \exp(-A)$$
 (5)

which may be solved directly for A. The solution is A = 0.0017256, which is put into the model equation to obtain the relationship:

$$P(x) = 1 - \exp\left[-0.0017256(1 + Sx)^2\right]$$
(6)

The remaining unknown parameter, S, is then estimated by fitting the equation above to the data in Table 2. An approximate maximum likelihood estimate of 0.922 is obtained. The model's goodness of fit is also shown in Table 2. The expected values are too small to conduct a formal X^2 goodness-of-fit test. However, it is apparent that the model is not underestimating the tumor rate in the experimental range.

The low-dose linear term from this model may be expressed in terms of the parameter values as 2AS, which must be greater than zero because the background rate A is always greater than zero and S is greater than zero for all positive dose-response relationships. The low-dose linear term in animal exposure units (mg/kg/day) for a 140-day (30 + 110) experiment is thus

$$q_1 = (2)(0.001723)(0.922) = 0.00318 (mg/kg/day)^{-1}$$
 (7)

Two adjustments are necessary to translate this into a human potency value. First, the risk must be adjusted to take into account constant exposure throughout one's lifetime. It is assumed that 1.5 mice years equal 70 human years (i.e., a lifetime) and 1.5 mice years)(365 days/year) = 548 days. The U.S. EPA's standard procedures for less than full lifetime followup yield an adjustment factor of $(548/140)^3 = 59.97$. Second, it is standard practice to calculate species-equivalent exposure units on a mg/ surface area basis. To convert our estimate to these units, we multiply by the additional adjustment factor of $(60/0.034)^{1/3} =$ 12.08, where 60 and 0.034 kg are the weights of an average human and CFW mouse, respectively. After making these two adjustments, the human potency factor is estimated to be:

$$q_1 = (0.00318)(59.97)(12.08) = 2.30 (mg/kg/day)^{-1}$$
 (8)

for human exposure. This value can be compared to the 95% upper-bound estimate of 11.53 (mg/kg/day)⁻¹ obtained by the U.S. EPA's contractor, which is not an actual estimate; it is only

the upper-bound estimate of the actual values and is approximately five times greater than the linear point estimate obtained here.

Dose-Response Relationship for Inhalation Exposure to B[a]P

Studies conducted to assess the risk of cancer posed by airborne B[a]P tend, for obvious reasons, to employ inhalation as the route of exposure. Such studies, however, face difficult methodological problems. Intratracheal instillation of B[a]P alone or in combination with other agents is therefore often substituted for inhalation. Although much valuable qualitative information has been obtained by this approach, its use in quantitative risk assessments has not met with much success.

Most carcinogenesis bioassays in which B[a]P has been administered via inhalation exposure have yielded negative results. There are several exceptions. Most notably, a positive response was obtained in rats using a combination of B[a]P and the atmospheric irritant sulfur dioxide; sulfur dioxide by itself was not carcinogenic.²² The tumors induced in this experiment were squamous cell carcinomas; a proportion of the bronchogenic carcinomas found in humans are of this type.

A well-conducted study by Thyssen *et al.*²³ provides the most clearcut evidence of the dose-response relationship between inhaled B[a]P and tumorigenesis. In this experiment, Syrian golden hamsters were exposed throughout their lives to B[a]P by means of a sodium chloride aerosol for 4.5 hr per day, 7 days/week, for 10 weeks and for 3 hr/day thereafter. Respiratory tract tumors were induced in the nasal cavity, larynx and trachea. The dose-response relationship obtained for these tumors is shown in Table 3.

 Table 3

 Data Used to Estimate Dose-Response Relationship Between

 Inhaled B[a]P and Respiratory Tract Tumors

Exposure	Average	Effective	Number of tract	respiratory tumors
rate (x) (mg B[a]P/m ³)	survival (t) (in weeks)	number exposed	Predicted	Observed
0	96.4	27	0.73	0
2.2	95.2	27	1.88	0
9.5	96.4	26	9.06	9
46.5	59.5	25	12.59	13

Note: Based on two-stage, dose- and time-dependent, identical transition rate model:

 $P(\mathbf{x},t) = 1 - \exp[-0.000115(1 + 0.312\mathbf{x})^{2}][\exp(0.057t) - 1 - 0.057t]$ Source: Thysen *et al.*¹¹

Source: Thyssen et al.

Using the average survival time as the length of observation, the two-stage model with identical transition rates and variable attained ages was fitted to the observed data using an approximate method. The goodness of fit is demonstrated in Table 3, where a x^2 of 2.81 with 1 = (4-3) degree of freedom is obtained, which implies that the observed data are not inconsistent with the model at the p > .05 level. The risk at the end of an average lifetime was obtained from the equation shown in Table 3 by evaluating P(x,t) at t = 96.4 weeks, the average survival time in the control population. This gives the following time-independent lifetime risk relationship:

$$P(x) = 1 - \exp[-0.0272(1 + 0.312x)^2]$$
(9)

For low levels of exposure, the linear term of the model times the exposure level is a close approximation of the estimated risk. The linear term in this case may be expressed as:

$$q_1 = (2) (.0272) (0.312) = 0.0170 (mg B[a]P/m^3]^{-1}$$
 (10)

To extrapolate this value to exposure by humans for 24 hr/day, the average length of exposure per day over the approximate 2-yr experimental period is calculated. The weighted mean of the two exposure periods is:

[(10) (4.5) + (92)(3)]/102 = 3.147 hr/day. Thus, exposure 24 hr/. day renders a potency value of:

$$q_1 = (0.0170) (24/3.147) = 0.1295 (mg B[a]P/m^3]^{-1}$$
 (11)

This calculation is based on the assumption that inhalation exposures are equivalent across species. To convert this exposure level to $(mg/kg/day)^{-1}$ so as to compare it to exposure via ingestion, we assume that the absorption rates for inhalation and ingestion are the same and that the average person weighs 70 kg and inhales 20 m³ air per day. Under these assumptions, exposure to 1 mg/m³ for 24 hr results in an exposure level of $1 \cdot 20/70 = 0.2857$ mg/kg/day. Thus, on a mg/kg/day basis, the estimated slope is:

$$q_1 = 0.1295/0.2857 = 0.4533 (mg/kg/day)^{-1}$$
 (12)

This value is considerably smaller than the U.S. EPA's estimate of 6.11 (mg/kg/day)⁻¹, which is based upon an adjustment for difference in species metabolism that is questionable.

The next section describes the model that was developed to estimate relative carcinogenic potencies for mixtures of PAHs.

ESTIMATION OF THE JOINT CARCINOGENIC RESPONSE OF THE TOTAL PAH EXPOSURE

The relative potency of the jth carcinogenic PAH compared to the potency of B[a]P at response level is defined as:

$$R_{j}(p) = x(p)/y_{j}(p)$$
 (13)

where x(p) and $y_j(p)$ are the number of exposure units of B[a]P and the jth carcinogenic PAH, respectively, required to produce a total carcinogenic response rate of p in the test system.

If the mechanism of action of B[a]P is the same as that of the jth carcinogenic PAH, it follows that:

$$\mathbf{R}_{\mathbf{j}}(\mathbf{p}) = \mathbf{R}_{\mathbf{j}} \tag{14}$$

(i.e., the relative potency is independent of the response level). This assumption is identical to the hypothesis of simple similar action²⁴ which often is used to estimate the joint response to multiple agents for various biological end points.

Under the hypothesis of simple similar action, it follows directly that the joint response to a set of carcinogenic PAHs is dependent upon the total PAH exposure, T, expressed in B[a]P equivalent units. This exposure may be written as:

$$T = \sum_{j=1}^{m} R_{j} y_{j} + x$$
(15)

where:

y,

- m = the total number of indicator PAHs exclusive of B[a]P,
 - = the exposure to the jth indicator PAH,
- x = exposure to B[a]P, and
- R_j = relative potency of the jth indicator PAH compared to B[a]P.

The probability of a cancer response given T is P(T), where $P(\cdot)$ is the dose-response relationship for B[a]P.

It was shown that the same functional relationship is consistent for the dose-response to B[a]P in mouse skin via skin-painting, hamster lung via inhalation and mouse stomach via ingestion. Given this demonstrated experimental consistency and the underlying theoretical rationale for the mechanism of action of the PAHs, it is reasonable to assume that the same functional relationship exists for all animal test models. The parameter estimates would undoubtedly be species-tissue-dependent, but the underlying structural relationships should be the same.

Using the two-stage identical transition rate model developed for B[a]P, the dose-response relationship for a specified test system can be expressed as:

$$P(x) = 1 - \exp(-A(1 + Sx)^2)$$
(16)

for B[a]P and as:

$$P(y_j) = 1 - \exp - A(1 + SR_j y_j)^2 j = 1, 2, ..., m$$
(17)

for the carcinogenic PAHs.

It is possible to obtain 100% efficient estimates of the R_j values by joint maximum likelihood estimation. However, such estimation procedures are time-consuming to develop and lie beyond the scope of the present project. Fortunately, a simple approximation for the estimates of the R_j values can be obtained.

We first estimate the value A from the control data. It can be shown that the final potency estimates are not particularly sensitive to this estimate. Given the estimated value of A, the terms SR_j can be estimated by an approximate goodness-of-fit procedure for each PAH for which data are available. The parameter S is estimated in a comparable manner using B[a]P dose-response data. The final relative potency estimates for R_j , which are independent of the animal test system used, are obtained from the ratio of the estimates for SR_j and S, determined from the jth PAH and B[a]P, respectively.

For many test systems, the highest dose may be the least relevant for determining potency, because of its association with acute toxicity, activation of cell proliferation mechanisms and/or saturation of metabolism or local penetration. When the highest dose yields a level that is inconsistent with the assumed dose-response model, it will not be used in estimating the parameters. In other situations, only a single dose level for B[a]P may be available. In this case, if B[a]P gives a high response, a more stable estimate may be obtained by simply using the PAH exposure level that gives the closest response rate to that of B[a]P. Even when a control value and a single response for B[a]P and the jth carcinogenic PAH are the only values available, it is possible to obtain an estimate of the relative potency. To demonstrate how such estimates can be obtained, consider the following limited response data.

	18	ble	4	
Obs	erv	ed	Re	ite

Agent	Exposure	Response
Control	0	r _o /n _o
B[a]P	x	r/n
jth PAH	Уј	rj/nj

An estimate for the relative potencies can be obtained by equating the observed rate with the function response. This results in the equations:

 $r_0/n_0 = 1 - \exp - A$ (18)

$$r/n = 1 - \exp(-A(1 + Sx)^2)$$
 (19)

$$r_j/n_j = 1 - \exp - A(1 + SR_j y_j)^2 j = 1, ..., m$$
 (20)

which can be solved algebraically by hierarchical substitution of the parameter estimates for A and S into the equation defining the relative potencies. This approach yields the algebraic solution:

$$R_{j} = \frac{x}{y_{j}} \frac{[\ln(1-r_{j}/n_{j})/\ln(1-r_{0}/n_{0})]^{\frac{1}{2}} - 1}{[\ln(1-r/n)/\ln(1-r_{0}/n_{0})]^{\frac{1}{2}} - 1} \quad j = 1, 2, ..., m \quad (21)$$

In the next section, the relative potency values (R_j) are estimated for chemicals expected to be present at waste sites. We also present an example of the extent to which estimates of risk can differ using the new method compared to the U.S. EPA's standard approach.

COMPARATIVE POTENCY ESTIMATES

The number of quantitative evaluations of the carcinogenicity of PAHs in comparison to B[a]P is somewhat limited. In the studies that have been selected to form the basis for comparative potency estimates, B[a]P was tested in the same bioassay system as the other PAHs in the same laboratory and at the same time. The following table lists the comparative potencies that have been derived in several studies for a number of PAHs commonly found at environmental waste sites.

	Table 5				
Summary of Relative Potency	Estimates	Derived	for	Indicator	PAHs

Benzo[a]pyrene	1.0
Benz[a]anthracene	0.145°
Benzo[b]fluoranthene	0.140 ^a
Benzo[k]fluoranthene	0.066 ^a
Benzo[ghi]perylene	0.022 ^a
Chrysene	0.0044d
Dibenz[ah]anthracene	2.82 ^b
Indeno[1,2,3-cd]pyrene	0.232 ^a
References:	

a. Deutsch-Wenzel et al.25

b. Pfeiffer²⁶

c. Bingham and Falk²⁷

d. Wynder and Hoffmann²⁸

The following example illustrates how cancer risks due to exposure to a mixture of PAHs can be estimated using comparative potencies or using the standard U.S. EPA upper-bound approach.

Assume that an individual was exposed via inhalation to the mixture of PAHs given in the following table.

Table 6 Results of Cancer Risks from PAH Exposure

РАН	Exposure level mg/kg/day (x)	Relative potency (Rj)	B[a]P equivalent units (R _{jx})
Benzo[a]pyrene	0.0012	1.0000	0.00120
Chrysene	0.0105	0.0044	0.00005
Dibenz[ah]anthracene	0.0001	2.8200	0.00028
Benzo[k]fluoranthene	0.0010	0.0660	0.00007
Benzo[b]fluoranthene	0.0010	0.1400	0.00014
Benz[a]anthracene	0.0014	0.1450	0.00020
Total	0.0152		0.00194

Using the upper-bound approach, an estimate of risk is obtained:

$$6.11 \times 10^{-3} \times .0152 = 9.3 \times 10^{-5} \tag{22}$$

Using the alternative point estimate, the risk is estimated to be: $.453 \times 10^{-3} \times .00194 = 8.8 \times 10^{-7}$ (23)

or more than two orders of magnitude lower. In this example, the upper-bound approach would probably cause regulatory concern; the point estimate would most likely not trigger remedial action.

OBTAINING REGULATORY ACCEPTANCE OF A NEW APPROACH

Estimates of the risk of exposure to carcinogens are based upon a series of conservative assumptions chosen to protect human health. When information is limited, parameter values are chosen conservatively to ensure that their incorporation in a risk model does not lead to an underestimate of risk. However, when actual data are available that can be used to measure a parameter directly, this information can be supplied as an alternative to the upperbound assumption. Such improvements in precision usually result in a lower upper-bound risk. As a general rule, as the scientific depth of the knowledge base increases, risk estimates based upon that knowledge decrease for the same assumed exposure level. This concept is illustrated in Fig. 1. Nevertheless, just because an improved model has been developed does not mean that it will be adopted by highly precedent-bound regulatory agencies. Often, new approaches must be sold to the regulatory agency through such mechanisms as:

- · Outside review by prestigious unbiased review committees
- Presentations at scientific meetings
- · Publication in the peer review literature
- Formal and informal meetings and seminars with regulatory personnel

The relationships among such effort, the quality of the study and the effort expended in gaining acceptance are depicted in Fig. 2. Efforts expended in this direction can give a highly profitable return on the investment when the potential savings in remedial action are considered. A reduction in risk of one order of magnitude brought about by improvements in risk assessment methodology can lead to a 100-fold reduction in cleanup cost. The benefit-to-cost ratio for such an approach can be very large. Although generating extensive new biological information is costly, undertaking the kind of cleanup activities that might be recommended based on the upper-bound dose-response modeling approaches is even more costly. The general relationship between total cost of effort and risk is depicted in Fig. 3.



Figure 1 Relationship Between Improvements in Mathematical Dose-Response Model and Estimated Risk

CONCLUSIONS

Biological parameters used in quantitative risk assessments should not be treated as fixed physical constants; rather, they should be viewed as crude approximations that can be altered by more extensive analysis and experimentation. Such effort usually will result in a reduction of perceived risk and a potentially large saving in remedial action costs. One example of where such an approach could result in considerable savings is in sites where ex-



Relationship Between Probability of a Result Being Adopted and Effort and Quality



Figure 3 Relationship Between Costs and Extent of Modeling Studies

posure to multiple PAHs is a potential problem. It was shown that alterations in the B[a]P dose-response models and the establishment of B[a]P-equivalent toxicities for other PAH exposures could reduce the theoretical risk by several orders of magnitude. It will be necessary to exert considerable persuasive effort, through formal and informal scientific channels, to gain acceptance of such new approaches by regulatory agencies.

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The Use of Geographic Information Systems as an Interdisciplinary Tool in Smelter Site Remediations

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ABSTRACT

Geographic Information Systems (GIS) represent an emerging technology that, in recent years, has been applied progressively to a variety of environmental studies. GIS's ability to flexibly integrate numerous technical considerations from several disciplines into a usable format promises to enhance traditional management and decision-making processes in CERCLA¹ projects. In this paper, two applications of GIS technology to similar toxic waste sites are presented. The first is a classroom application to a relatively straightforward soils contamination problem involving a secondary lead smelter. It provides a classical demonstration of GIS capabilities in an academically controlled setting. The second case history is an ongoing CERCLA project involving a huge primary lead-zinc smelting complex and 21 mi² of potentially affected properties, including massive impoundments of mine wastes, a major river drainage and four cities.

Several lessons can be learned in comparing these case histories. These include classical problems of "academic versus real world" applications and the magnitude of difference in technical sophistication dictated by the relative size and complexity of the sites. However, equally important lessons concern CERCLA-specific institutional problems associated with inherent drawbacks in providing interdisciplinary ends-directed analysis in a litigious expertladen environment.

INTRODUCTION

A Geographic Information System (GIS) might be described as a universal processor of spatial data in map format. However, GIS is a schizophrenic technology. It suffers an identity crisis and often is misunderstood in origin, purpose and application. Estes² has reviewed several systems and found a variety of formats that differ substantially in capabilities and methods of data storage and manipulation. Five essential components of a computerbased GIS are described as: (I) data encoding and input processing, (2) data management, (3) data retrieval, (4) data manipulation and analysis and (5) data display. GIS technology has evolved from and integrated aspects of several disciplines. University catalogs list GIS emphasis in Natural Resources Management, Geography, Environmental Studies, Geology, Cartography, Landscape Architecture, Remote Sensing, CAD-CAM (Computer Aided Design/Manufacturing) Laboratories, Engineering and other areas. This extensive list means that GIS has different meanings depending on the discipline and application. In this project, two allied GIS' were utilized. The Map Analysis Package (MAP)³ distributed for academic use by the Yale School of Forestry and Environmental Studies and pMAP4, a similar microcomputer package for professional use. Both are grid-based and store and manipulate maps in the form of fixed-size cells in Cartesian format.

The technology's unique asset in CERCLA application may be as a technical tool for interdisciplinary endeavors. Superfund projects offer immense multidisciplinary challenges. Severe technical problems are encountered in both site assessment and remedial design. Projects are often the focus of intense public concern and scrutiny. Community relations, education efforts and political considerations sometimes become as demanding as the technical issues. Commonly, major CERCLA projects are litigation-driven and managed as lawsuits rather than engineering projects.

Congressional mandates and U.S. EPA policies place unmerciful management constraints on site personnel. The certainty necessary in cleanup and disposal plans, rigid closure specifications and "bombproof" quality assurance and control (QA/QC) requirements for litigation leave site managers with few ready technologies and little flexibility in completing difficult tasks. Ultimately, this situation has resulted in massive production of paper products. It is much easier to assess than it is to address toxic waste problems. Reports and site assessments are proliferate. It is easier yet to critique and review, making reassessments even more evident. Finally, CERCLA projects are run by committees of U.S. EPA and state personnel, Potential Responsible Parties and numerous consultants. These circumstances invite experts to find basic data insufficiencies, and millions of dollars are spent on studies, reassessments and studies of studies.

Such problems are common to bureaucracies faced with formulating major technical strategies. Baritz,⁵ in reviewing the failures of such institutions, noted, "Although efficiency is a means, not an end, there is an overwhelming likelihood that bureaucracies will sooner or later, usually sooner, confuse means and ends, or will simply lose sight of the organization objectives in the continuous search for higher levels of efficiency." In CERCLA, means-oriented policies have evolved into an obsession with methodology and assessments to the point of avoiding ends-oriented cleanup questions. Introducing a new technology, such as GIS, that cuts across several disciplines in an expert means-directed climate of "study, critique, but don't act" is a difficult proposition.

CASE HISTORY I — DALLAS/RSR SMELTER

This case history was developed for a senior/graduate level course conducted by the College of Engineering at the University of Idaho and Washington State University in the spring of 1986 entitled "Computer-Assisted Spatial Analysis of Environmental Problems."

Background

The RSR facility was a secondary smelter, located in West

Dallas, Texas, and was principally involved in recovering lead from scrap batteries. It operated from the World War II era until 1984. Air pollution from the complex was largely uncontrolled until primary point source and sanitary emission controls were installed from 1968 to 1973. Major enforcement actions undertaken in 1974-75 resulted in additional emissions reduction by 1976. However, subsequent ambient monitoring showed poor performance and best available smelter control capacity was not installed until 1980.

This long history of uncontrolled and excessive emissions resulted in gross contamination of local soils by lead particulate. The smelter was located adjacent to major residential areas. A 400-acre area northwest of the complex contained small single family dwellings housing approximately 2000 people. Northeast of the smelter was one of the city's largest public housing projects including several thousand units within 1 mile of the complex. Fig. 1 shows a map of land use in the vicinity.



Figure 1 Land Use in Vicinity of RSR Smelter, Dallas, Texas

In 1982 Federal and local government agents cooperated in a study of childhood blood lead absorption and environmental contamination in the area. Fourteen percent of the preschool children living within 0.5 miles of the smelter were found to have blood lead absorption levels in excess of the federal Centers for Disease Control criterion of 25 μ g/dl whole blood.⁶ Concurrent analyses suggested that the excess blood lead levels were associated with elevated residual soils and current airborne lead contamination in the neighborhood.^{7,8} Subsequent court-ordered enforcement actions required the removal and replacement of contaminated soils from surrounding residential areas and imposed rigid emission restrictions on the smelter.⁹ Civil litigation also resulted in large recoveries for health and property damage to local citizens. The complex ceased operations in 1984.

GIS Procedures

Data Base Development

Fig. 2 illustrates the four basic input data "maps" created for

subsequent GIS analyses in this study. These were: (a) Soils Map plotting the location and concentration of soil lead samples obtained by the EPA, (b) the Landuse/Features Map showing landuse characteristics, (c) the Housing Map showing the distribution of dwelling types and (d) the Street Map showing the major streets in the Study Area. These maps fix the locational aspects of the input data. Other attributes of the same features are retained in a relational data base. New maps are created by reclassification as illustrated in the figures and discussion below. Attribute data for the Landuse/Features Map include zoning categories, principal use and percent of bare ground surface. Housing attributes include housing type, unit and per unit population density and ownership; streets could be reclassified by type, number of lanes, travel times and traffic volume.

Determining Hazard Zones

The first major classroom analysis was to determine hazard zones based on projected soil lead levels. Spatial estimation and contouring of the soils sample grid were accomplished by a variety of techniques. The course included "nearest neighbor," "weighted distance" (inverse distance squared weighting), "moving-average" (a method to artificially smooth complex surfaces)¹⁰ and "Kriging" methodologies.¹¹ These methods all resulted in patterns of contamination similar to those developed by the U.S. EPA.^{7,12} Candidate hazard zones were developed by reclassifying areas within specified isopleths. Several methodologies were utilized, and zone definitions were based on both mean concentration estimates and the probabilities of exceeding certain limits. Students designated four categorical zones of contamination or risk (i.e., severe, moderate, mild and none) as shown in Fig. 3.



Figure 2 Four Base Maps Comprising GIS Data Base for Smelter Site

Populations and Properties Affected

After action zones were defined those populations and properties found within the zone boundaries were assessed. This definition was accomplished by simple GIS processing that overlaid the hazard zone map on the desired attribute maps and tabulates



Figure 3 Conversion of Isoplethic Estimates to Hazard Zones

values within zone boundaries. Cross-tabulations were developed for numbers of persons, numbers of dwellings and types of dwellings per hazard zone, number of persons per housing type per hazard zone, etc. Results of representative analysis are shown in Table 1.

	Table	1				
Cross-tabulation of	Population and	Housing	Туре	by	Hazard	Zone

Hazard Zone	Public Housing	Private Housing	Total
Severe	1872	544	2416
Moderate	2304	676	2980
Mild	3888	1940	5828
	8064	3160	11224

Students utilized these results in considering potential remedies. It was obvious that those areas where major benefits can be developed do not neatly follow the hazard zone boundaries. In considering "remedial" zones (in contrast to "hazard" zones), the real property and population density configurations become equally important. Remedial zones eventually are defined based on the intersections of hazard and property and population attribute maps. Moreover, when considering the eventual costing and design ramifications of remediation, specific geographic units based on land use attributes are more efficient and defensible determinants of remedial zones than are contamination estimates. Several methods of designing remedial zones are available in the GIS. The simplest involve reclassifying geographic land use or population units by reversing the overlay procedure above. Specific geographic areas are designated as remedial zones based on the distribution of hazard levels within their boundaries. Reclassification can be based on the mean, median, majority or maximum hazard encountered or some combination of the several variables involved. A second, more elegant, method is to use the moving average surface smoothing algorithm to "mold" hazard zones around desired land use and population units. The result of either of these methods is a map of Remediation Zones indicating areas where some level of corrective action is desired. Fig. 4 shows example Remedial Zones.

Costing Remedial Scenarios

Cleanup scenarios were then developed for the several remediation zones. Table 2 shows one such scenario similar to the actual cleanup accomplished in West Dallas. GIS reclassification and cross-tabulation procedures were used to develop preliminary cost estimates for the scenarios. As illustrated in Fig. 5, unit cost estimates were applied to individual property parcels through reclassification of the attribute and contamination maps. Various assumptions were developed regarding disposal requirements for excavated soils based on projected concentrations, the costs of excavation and removal associated with access based on the dwelling type, the cost of health and safety precautions based on concentration and population proximity, excavation volumes based on housing density and type and costs for street berm and housing cleanup based on type. The cost results of the Fig. 5 scenario are





Figure 4 Remedial Zones in Vicinity of the RSR Smelter, Dallas, Texas

shown in Table 3. Numerous scenarios can be accomplished quickly by simply changing the reclassification assumptions and repeating the Fig. 5 procedure.

 Table 2

 Example Remedial Scenario for Figure 4

Remedial Zone	Proposed Remedy
A-Private Housing	6" soil removal and replace-water subsidy
A-Public Housing	6" soil removal and replace - attics cleaned
B-Private Housing	Rototill/Establish vegetative cover-water subsidy
B-Public Housing	Rototill/Establish vegetative cover
B-Parks/Undev.	Rototill/Establish vegetative cover
C-Commercial/	Zoning restrictions
Industrial	Pavement washing
D-Smelter	"Hazardous Waste" Removal Pave all traffic/storage areas Emissions Reductions

Modeling Cleanup Schedules

The final course exercise modeled the movement of cleanup crews and equipment utilizing network transportation analyses available with the GIS. Truck movement through the community to disposal areas was analyzed by reclassification of the street map into time/travel cost maps. Various disposal site locations and movement constraints on cleanup crews were considered. The interdisciplinary aspects of a hostile community were interjected into the last analyses by eliminating certain streets as access and transportation routes, imposing artifically low speed-limits and



Figure 5 Map Analyses Used to Estimate Costs of Various Cleanup Scenarios Detailed in Tables 3a-c

Table 3 Typical Remedial Scenario Cost Cross-tabulations

3a-Soil Remedial Costs by Hazard Zone

Hazard Zone	Area (Ac)	Pickup (\$K)	Disposal (\$K)	Total (\$K)

Severe	168	440	593	1033
Hoderate	202	484	543	1027
Mild	566	1 198	367	1565
	936	2122	1503	3625

3b-Soil Remedial Costs by Hazard Zone and Landuse Class

Hazard Zone	Residential	Soils Cost Parks/Undev.	(\$K) Commercial/Indus.	Totals
Severe	699	40	294	1033
Moderate	712	241	74	1027
Mild	1129	239	197	1565
	2540	520	565	3625

3c-Soil Remedial Costs by Remedial Zone

Remedial Zone	Soil Cost (\$K)		
A-Private	333		
A-Public	399		
B-Private	820		
B-Public	988		
B-Park/Undev.	520		
C-Commercial/Indus.	565		
	36.36		

time-consuming precautionary measures and utilizing alternate disposal sites to avoid protesters. The cost of these actions in both time and dollars was evaluated utilizing the GIS procedures.

CASE HISTORY II — THE BUNKER HILL CERCLA SITE

Background

The 21 m² area designated for the Bunker Hill Remedial Investigation and Feasibility Study (RI/FS) represents one of the nation's largest and most complex CERCLA sites. The area is located in a steep mountain valley drainage in northern Idaho and has been the center of one of the world's most active and productive lead, zinc and silver industries for over a century. The current site boundaries encompass: four incorporated cities; an affected population of more than 5000 persons; a large river floodplain; an



Figure 6 Soils Related Features of Bunker Hill Smelter Site, Kellogg, Idaho

immense, largely dormant industrial facility including a major mine and mill works, primary lead smelter, primary zinc smelter, ammonium phosphate fertilizer plant, over 160 acres of impounded tailings and several hundred acres of contaminated soils and waste piles. Fig. 6 shows several soils-related features of this site.

A century of mining, milling and smelting has resulted in widespread contamination of soils throughout the area. Excessive levels of heavy metals in area soils have resulted from a combination of waterborne wastes deposited by floods or discharge impoundments, deposition of airborne emissions from nearly seventy years of smelter activities and direct dumping of solid waste materials. Several epidemiological studies conducted over the last decade have shown excess levels of lead in the blood of area children.^{16,17,18} The most recent studies have concluded that contaminated soils are currently the largest contributor to that excess absorption. Children access the metals in area soils either by direct contact or through contact with wind-blown dust from barren areas that contributes to house dust and contaminates foodstuff.

GIS Procedures

Data Base Development

A comprehensive Data Base Management and Analysis System has been developed for use in this project. Fig. 7 shows the basic components of that system. This area has been studied for a variety of reasons for a long period of time. To maximally exploit the historical data base, an exhaustive records search was conducted and an extensive site library was established.¹³ More than 2 dozen state, federal, university and private entities that had conducted previous studies were visited. More than 100 theses and dissertations, 20 years of regulatory records and several hundred thousand dollars worth of data collected in business, legal, regulatory and research efforts were reviewed and logged. Standard bibliographic data were entered, and the information was indexed and cross-referenced by several subject identifiers.

Draft data quality criteria for review and use of historical information in the CERCLA process were developed by U.S. EPA technical and legal staff and contractors. The first of many CERCLA institutional problems was encountered in applying these criteria. Of the more than 3,000 items reviewed, only one met the initial policy criteria. This nonsensical policy was soon revised to allow specific use of some data and standards to verify others. All the available material was reviewed, and two major historical site characterization documents were developed.^{14,15}

Selected Data Analyses

Residential soils in these communities are severely contaminated. In a comprehensive 1983 Lead Health Study, 90% of residences within 1 mile of the smelter were found to have lead levels in excess of 1000 ppm; 70% of those exceeded 2500 ppm. (Less than 10% were greater than 1000 ppm in Dallas in 1982.) Soils in this survey were extensively sampled in a well-controlled effort similar to the Dallas studies. It was thought that application of the procedures and techniques developed for the Dallas situation might accelerate the residential soils portion of the RI/FS.

The basic strategy was to utilize these historical data to develop preliminary hazard zone estimates to develop a conceptual methodology to assess population and properties affected and to



Figure 7 Information Management System Used at Bunker Hill Smelter Site

pose potential remedies. The specific goal was to involve local officials and property owners in developing and evaluating conceptual alternatives early in the process. Additional sampling and analytical needs could be determined as those plans developed. Although there was some concern with mis-categorization in using historical data projections, it was felt that the extreme levels of contamination would largely offset any inherent spatial bias for conceptual purposes. However, a basic conflict in CERCLA policy hampered this effort. U.S. EPA policy disallowed sample collection prior to the completion of a work plan for the entire site. Data Quality Criteria, however, prohibited use of historical data until additional sampling had verified adequacy. Because it would take nearly 2 years to develop a full site work plan, a compromise program of developing a GIS data base of soils information, briefly assessing the available data and designing a study to verify reproducibility was adopted.

Data including roads, residential areas and the results of several sample surveys were digitized and input to the GIS. Soil contamination data from two large earlier studies (1974 and 1983) were examined in a cursory manner similar to the classroom contouring exercise discussed in the previous case history. These techniques provided several initial soils concentration estimates for six metals in an historical context. All of the characterizations were automatically routed to the GIS data base as cell by cell estimates of contaminant concentration. Specific land use areas were masked-out, and the remaining estimates were utilized for simple contouring and comparative analyses to aid in design of the verification survey and the eventual site work plan. Some examples follow:

Temporal Comparisons

An interesting result was obtained by simply dividing the 1983 contamination surface by the similar 1974 surface for each metal. This comparison consistently suggested that soil lead levels in most areas decreased about 25% during the intervening decade. Soil cadmium concentrations, however, seem to have increased by a similar amount. It seems that, in the top 1 in. of soil, the ratio of cadmium to lead increased by 50% over the 9 yr period. This suggestion of significant cadmium accumulation in the organic soil horizon is critical and could have enormous effect on the effectiveness of eventual remedies. Even by this simplistic analysis, it was clear that investigation of this possible phenomenon should be included in the work plan and selection of any remedy. It was equally clear that the 10-yr old data, at least, would be of little use in characterizing current soils contamination.

Comparisons of Spatial Estimation Methods

Flatman *et al.*¹² have provided a cogent discussion of the underlying purpose of contouring analyses and the important consideration of avoiding "false negatives" in the spatial based prediction of contamination data. That is, analytical methods should be directed at avoiding labels such as "clean" for areas that are, in reality, contaminated. The method advocated (Probabilistic Kriging) was actually utilized with the Dallas data in 1983 in defining Class Action boundaries in a Civil Property suit.¹⁹ In that action, 40 independent samples were collected to test the reliability of the contour generated zones (unpublished data).

In assessing the effectiveness of the different spatial estimation methods in the context of avoiding "false negatives," it was interesting to note that the best performer was neither concentration nor Probabilistic Kriging, but the artificially smoothed surface. The reason is evident. Surface smoothness is achieved by taking from peaks and adding to valleys. This statistical "fill and borrow" technique actually spreads contours and causes areas that are slightly below zone criteria to be included, but seldom moves higher values to lower zones. Similarly, all methods tend to agree on zone categorization in interior locations, but tend to differ near zone boundaries. One of the most effective methods of selecting areas of greatest uncertainty (with respect to "false negatives") seems to be where methods disagree. Those areas readily can be identified by comparison of the estimation surfaces among methods by GIS techniques. That analysis was accomplished with the 1983 sample data. This and other GIS derived categorical criteria were offered as elements in locating verification survey sample points.

Results

The seemingly unorthodox analyses were, of course, subject to geostatistical crucifixion. It is likely that a simple re-analysis of 10-15% of the original sample sites and a similar number of randomly selected new homes would have validated the data base, satisfied critics and allowed spatial analysis of the resultant data. Unfortunately, the introduction of these preliminary analyses, that were easily obtained and arguably could achieve a better product, attracted considerable criticism and resulted in a complete revamping of project strategy.

GIS analyses (as opposed to data input) are quick and inexpensive. One hundred and eight characterizations encompassing six metals, three cities, three different surveys and three methodologies, were developed, compared and analyzed as discussed above, in less than 24 man hours by automated techniques. By comparison, an additional 40 man hours were required to produce nine ordinary Kriging analyses, and additional geostatistical considerations were curtailed. The U.S. EPA spent several times the expense of obtaining these analyses in, to a certain extent, irrelevant reviews of the methodology. These analyses were simple and reached simple conclusions. The temporal comparison did no more than suggest areas where additional work should be focused. The comparisons among spatial estimation methods and categorical intersections of qualitative uncertainty criteria tried only to locate the limited additional sampling allowed in areas where it would be most helpful.

Several discussions, reviews and responses reminiscent of the classical debate of "how many angels fit on the head of a pin" followed. It soon became evident that actual sampling would cost less than fueling the methodological bickering. A wise project of-ficer obtained a change in U.S. EPA policy allowing advance sampling of all residential soils. In this case, at least, the application of GIS analyses resulted in more rational U.S. EPA policy, albeit indirectly.

CONCLUSIONS

The variety and sophistication of the analyses accomplished with a relatively small data base in the Dallas case history demonstate the flexibility and capability of GIS. Despite its early identity crisis and less than enthusiastic response from rigid disciplinarians, GIS promises to do for the analysis of maps, aerial photography and spatial data, what hand calculators have done for engineers and field investigators. The level of sophistication in these endeavors will range from the simplist of "quickand-dirty looks" to complex modeling efforts, and some forms of GIS will perform well across the spectra.

However, in beginning to use GIS as a tool in a real project, other problems surfaced. The GIS's flexibility and usefulness as a tool that emulates and assists in logical analyses of diverse data sources makes it particularly amenable to forms of semiquantitative interdisciplinary applications. Such analyses, however, are vulnerable to esoteric criticism from those disciplines that are bridged. Such critical review is expected in an academic or research environment and is, indeed, healthy and conducive to development of a better technology.

In the CERCLA climate, however, such treatment may be neither healthy nor wise. Some strict disciplinary experts either are unaware of, or refuse to recognize, the underlying strategy and limited nature of the conclusions drawn with GIS or other interdisciplinary analyses. Their critiques, when applied out of context, can be irrelevantly but nevertheless severely damaging to project credibility in litigation. This is most unfortunate, as many of the questions that must be resolved in remediation never can have the level of certainty that technical disciplines impose in assessment activities. Further, the standard of proof to justify decision-making in litigation differs substantially from scientific methodological criteria. The basic steps in both these case histories, and in CERCLA projects in general, might be described as: (1) the technical decisions made in investigation and assessment, (2) the decisions involving remedial alternatives and boundaries and (3) defending those decisions in cost recovery. The major challenges are in the second area where the decision-making process is forced beyond the security of technical certainty,

In the Dallas classroom example, students were quick to learn that, however well they fine-tuned hazard zones, the decision as to "remedial zones" was difficult and involved qualitative and interdisciplinary subjectivity. Similarly, in the actual Dallas cleanup, a comprehensive analysis of the soils contaminant distribution was developed by federal personnel. The geostatistics were to the highest level of precision. However, no federal agency accepted the responsibility of determining remedial zones. Those decisions were made in settlement negotiations involving state, local and private litigant's attorneys with limited technical assistance.

GIS analyses might have provided a great service in those negotiations. Classroom students found that the best definition of remedial zones resulted from evaluating the effects of alternate scenarios applying different constraints and interdisciplinary considerations. Similar calculations were, doubtless, hand-labored in the actual settlement. Better, quicker and more sophisticated "looks" could have been provided with GIS. In the Bunker Hill situation, continual "backsliding" to a means-directed project is evident. It is clear, with practical certainty, that residential soils in this area are contaminated 4 to 40 times those levels remediated in Dallas. If the Dallas cleanup model conceptually applies to Bunker Hill, remediation will be based largely on land use and population distribution criteria. Because most of the residential areas in three cities are sorely contaminated, cleanup priority will be directed to property parcels that the population can or wishes to access. Although contaminant levels are more severe than in Dallas, interdisciplinary considerations other than pollutant distributions will play a larger role in determining remedial zones and schedules.

In order to facilitate this cleanup, contaminant levels should be verified as soon as possible. Basic information regarding current and projected land use and population characteristics should be developed and identification of, negotiation with and assimilation of the decision-making entities into the project should be encouraged. Additionally, the interests of these vital participants will go far beyond the geostatistical certainty of the contamination estimates on particular parcels of land. Whether children will inhabit the property, property values, taxes, utilities, economic development potential, zoning and liabilities will be important considerations to landowner representatives.

Comprehensive efforts should be made to develop answers to such questions. GIS has great potential to provide such services through its ability to quickly evaluate numerous scenarios. GIS well may be a key technical tool in facilitating resolutions to the many non-technical problems encountered in remedial planning and negotiations. However, effective use of GIS and other interdisciplinary technologies will be difficult in CERCLA projects unless they are recognized and judged as ends-directed tools.

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Improving the Implementation of Remedial Investigation/Feasibility Studies Using Computerized Expert Systems

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ABSTRACT

In this paper, the authors discuss how computerized knowledge-based or "expert" systems have numerous applications within the RI/FS process. These expert system applications combine traditional data bases with "knowledge bases" characteristic of expert systems. Actual results using the expert system concept on the U.S. EPA's Remedial Program are discussed to demonstrate how useful expert systems can be to the U.S. EPA in their remedial program. The development of one operational system, the Work Assignment/Work Plan Memorandum Generator, is discussed.

INTRODUCTION

Many of the programs implemented by the U.S. EPA involve collecting and evaluating technical data and using this data to develop limits for operating facilities or to promulgate general regulations. Most decisions made by the U.S. EPA (and their consultants) rely on the composite knowledge of technical experts and specialists, and many of these are completely amenable to development by computer aided engineering systems or expert or knowledge-based systems. In particular, many aspects of the U.S. EPA's remedial process and the Remedial Investigation/Feasibility Studies (R1/FS) used by the U.S. EPA to investigate CERCLA sites have great applicability for the use of these expert systems.

Expert systems are advanced computer programs that simulate human expertise to aid a user in the analysis of difficult and often complex problems. They differ from traditional computer programs in that they can simulate and integrate a far greater range of information-representation and information-processing mechanisms. The systems are developed in sophisticated programming languages and "shells" that speed programming and execution. The technology has evolved over the last several years to the point where large expert systems now can be implemented on microcomputer systems.

CDM Federal Programs Corporation (CDM) has extensive experience with the analysis of hazardous waste situations using computer and expert system techniques. We have worked closely with U.S. EPA program staff and have demonstrated the utility of expert systems in the RI/FS process. In our work for the U.S. EPA, we have shown how the use of this engineering analysis tool can save months out of a typical RI/FS schedule, streamline the administrative requirements of the process and also save considerable amounts of money. In this paper, we will present a short overview of the expert system technology, demonstrate the applicability of these systems to remedial investigations and describe in detail several technical applications which we have developed for use on CDM REM II remedial contract.

THE RI/FS PROCESS

In addition to establishing a fund for financing the cleanup of uncontrolled hazardous waste sites across the nation, CERCLA also required that procedures be established to evaluate remedies, to determine the appropriate extent of the remedy and to ensure that cost-effective remedial measures are developed which provide protection of public health and the environment.

One of the means used by the U.S. EPA to evaluate and remediate hazardous waste sites is the Remedial Investigation/Feasibility (RI/FS) Study process. The purpose of this process is to collect sufficient data to characterize a site so that feasible remedial actions can be evaluated, costed and eventually selected in a Record of Decision (ROD). The RI/FS process is part of the U.S. EPA's overall remedial program in which sites are evaluated, ranked for inclusion on the NCP and remediated through the Remedial Design and Action process.

The RI/FS process is an involved technical and administrative process through which site data are collected, validated and evaluated. A normal RI/FS often requires completion of over 40



Figure 1 The RI/FS Process and Potential Expert System Development
interrelated field and office activities, many of which require EPA or state involvement. A typical work flow for a normal RI/FS study is shown in Fig. 1.

RI/FS IMPLEMENTATION ISSUES

A typical RI/FS now takes slightly over 2 years from assignment to completion, i.e., the signing of a Record of Decision for that particular site. This time frame is months longer than originally envisioned by the U.S. EPA.

Besides the long duration for these studies there are other issues that often complicate the implementation of an RI/FS for the U.S. EPA. These include:

- Lack of experienced senior-level personnel
- Increasing administrative requirements
- Changing program requirements
- Regional and state implementation differences
- PRP negotiations

These issues, and others, can easily be addressed within the framework of an expert system or computer-aided engineering system. Rules for completion of parts or all of the RI/FS tasks can be developed and coded within an expert system. An expert system essentially captures the knowledge of selected experts within a narrow knowledge domain. For this reason, the expert judgment of key program people can be utilized more efficiently on a larger number of assignments using the expert system technique.

Administrative and regional variations can be defined within the expert system rule base, set up once and used routinely without the need to remember or keep track of the many different RI/FS execution options used by the states and regions.

And finally, new program requirements often alter the RI/FS decision-making process or modify current technical procedures. These types of changes can be changed once within the expert system, and the new program requirement can be implemented immediately without extensive training or development and transmittal of new guidance material.

The advantages of using expert systems in the U.S. EPA's remedial program have been demonstrated with the work CDM has completed. The many automated systems developed by CDM have shown that both administrative and technical applications can be effectively implemented using expert system technology.

Over the past year, we have worked closely with the U.S. EPA to identify CERCLA expert system applications and are now actively developing several of the high priority systems. The planning work we completed with the U.S. EPA led to a classification of potential expert system applications. These applications are also presented in Fig. 1. Additional details on some of these applications are discussed later in this paper.

EXPERT SYSTEM TECHNOLOGY

Expert systems form part of the broader discipline within computer science known as artificial intelligence (AI). While nearly every researcher has his or her own definition of this term, we define AI as the study of how to get computers to make choices we would regard as intelligent if those choices were made by human beings.

As AI research evolved, much of the development work focused on ways to store in the computer the large body of knowledge specific to a particular task, then to approach the task by combining pieces of this knowledge in relatively straightforward ways, and finally to keep track of the facts and line of reasoning employed so that the program could explain how it arrived at its results in much the same terms that a human expert would. This new research focus became known as "knowledge based systems," or "expert systems," and the people engaged in developing knowledge bases became known as "knowledge engineers."

The tasks which expert systems are built to address ordinarily will call on knowledge which is ill-defined, largely intuitive and a matter of exercising judgment rather than adhering to clearly formulated procedures. If the task had been clearly formalized, a conventional programming approach most likely would have been more appropriate. Because the problems expert systems seek to solve are of this nature, the bulk of the work that goes into their construction goes into understanding how the expert thinks. Thorough understanding of how the expert thinks will not come all at once, but is an important component of the knowledge engineering process so that the resulting system correctly models the expert's thought processes for an accepted percentage of applications.

An expert system contains two kinds of knowledge which are kept strictly segregated in the interests of efficiency. First, it has knowledge about logical inference and general problem solving methods; the part of the system that embodies this general knowledge is referred to as the "inference engine." The creators of an expert system usually will purchase most or all of the inference engine off the shelf so that they can concentrate on the second part of the system, where detailed knowledge about the problem domain is stored. This second part of the system is known as the "knowledge base."

The concept of a knowledge base is not to be confused with the familiar notion of a data base. A typical data base consists of raw data, of columns of numbers and names much like those in a financial spreadsheet. A knowledge base stores information at a higher, more conceptual level in the form of facts and rules; this information is not constrained to fit into any predefined matrix of rows and columns. In a system to draw up an employee health and safety plan for a CERCLA RI/FS, for example, the knowledge base would encompass facts and rules like the following:

• DATA: (1) The measured atmospheric concentration of toluene at the site is 734 mg/m³.

(2) Neoprene clothing will survive at least 1 hour of exposure to aliphatic hydrocarbons.

• RULE: If a substance can be classified as a combustible gas and the substance is present at the site and the oxygen concentration meter in a zone shows at least 19.5% oxygen and the combustible gas indicator in the zone reads 10% to 20% of LEL and an activity will involve work in that zone, then assign an additional person to that activity to monitor the combustible gas indicator.

Rules like the one just quoted, known as "if-then rules" or "production rules," are the most common form used for expert system rules. Another common type is the inheritance rule. For example, an inference engine that understood the operation of inheritance rules would take "An FID is a kind of monitoring device" to mean "All rules that apply to monitoring devices apply to FIDs." Special logical mechanisms like this allow many rules to be condensed to a few and improve the clarity and efficiency of the system.

The expert system's ability to deal with information at the level of knowledge rather than at the level of data has two beneficial side effects. In traditional computer systems, the programmer also might begin with a set of facts and rules, but he would have to translate them to the level of operations on simple data before the computer could understand them. Using expert system tools, he does not need to go through that translation. For those systems that are susceptible to the expert systems approach, this approach results in greatly reduced programming costs. Second, because the information is still in fact/rule form while the computer is working on it, the computer can explain what it is doing at each step in immediately comprehensible terms. It can quote the facts, rules and line of reasoning used to reach any of its conclusions or recommendations.

EXPERT SYSTEM DEVELOPMENT PROCESS

More formally, we can identify six steps in the knowledge engineering process (Fig. 2). First, the problem is defined. This identification process involves locating sources of information: experts, textbooks, reference manuals and guidance documents; steeping oneself in these materials to get a broad understanding of the field; and setting clear, realistic boundaries on the task the system is to perform. The scope of the task must be neither so narrow that a successfully built system will not be of significant practical value, nor so broad that the system cannot be built with currently available tools and within the resources committed to it. Second, the problem is conceptualized. The knowledgeable engineer determines the principal objects the expert thinks about, determines their important characteristics and asks the fundamental questions the expert would ask as he begins work on a problem. Third, the problem is formalized. A particular computer model is laid out for the concepts extracted in the second stage. Then the process enters the main cycle of knowledge engineering, incorporating several iterated steps: (1) interview the expert and extract new information; (2) express that information in the form of rules and enter the rules into the knowledge base; (3) test the revised system (the experts may be present at the more formal tests); and (4) conduct the next interview on the basis of the test results.



Figure 2 Expert System Development Process

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Expert systems have been successfully developed to deal with a wide variety of serious real world problems. They have been used, for example, to diagnose and prescribe for bacterial infections (MYCIN), configure minicomputer installations (XCON), reduce the structure of complex organic molecules (DENDRAL), and review geological data to recommend places to drill for oil (PROSPECTOR). As we will indicate, many of the component tasks of planning and administering a CERCLA R1/FS satisfy all our criteria.

CURRENT COMPUTER-BASED APPLICATIONS

Since the onset of the REM II contract, CDM has aggressively researched the role of automated systems in the CERCLA remedial process in order to make more efficient and effective use of available resources. These automated systems include both traditional applications for database and financial modeling as well as more advanced applications such as knowledge-based expert systems. The philosophy of systems development has been a modular approach so that the many parts may be used individually or together for building larger, integrated systems.

CONVENTIONAL SYSTEMS

The conventional micro- and minicomputer systems now in use include those for office automation, cost accounting and estimating, and various technical database systems. Two of the main database systems are REMTECH, the technical database, and the Chemical Compound database.

REMTECH is a relational database system developed to maintain large amounts of technical data from hazardous waste sites. The system resides on a VAX-11/785 minicomputer. Included are facilities to enter, edit and retrieve data related to on-site sampling and laboratory testing of samples. A microcomputer data entry system permits users to enter data locally on microcomputers to be verified and uploaded into the VAX database system. The file generation feature allows users to select data for numerous report formats or ASCII flat file generation. These flat files may be input to other VAX-based systems or may be downloaded to microcomputers for input to micro-based computer programs. These other types of programs include systems for graphics, statistics, reports and expert systems requiring these sampling data.

The Chemical Compound database system contains over 70 chemical, physical and biological properties for hundreds of compounds. Included is information relating to health hazards, flammability and reactivity characteristics, environmental properties and personnel protection and monitoring characteristics.

EXPERT SYSTEMS

The development of expert systems at CDM grew out of a need for increasingly more powerful, robust systems to aid the remedial planning activities of the REM II contract. The early expert system development was CDM sponsored research in order to determine the applicability of expert systems in the remedial process. These initial efforts proved fruitful, leading to further development of in-house systems and a U.S. EPA Work Assignment for expert system development.

One such system is the Health and Safety expert system which is being used to generate concise, practical health and safety plans (HSP). The purpose of the HSP is to establish site-specific requirements for protecting the health and safety of personnel during all activities conducted at a site. The primary data required as input to the system includes site-specific information such as location, site size and type, a description of the tasks to be completed and known contaminants and their quantities. The output of the system includes contaminants of concern including health effects, required personal protection apparel, equipment required and recommended monitoring procedures. Many of these data, such as the chemical data, reside in conventional databases accessed by the expert system.

A current U.S. EPA Work Assignment for expert system development addresses the need of the U.S. EPA to estimate schedules and financial requirements for all of its remedial assignments. The purpose of this assignment is to investigate systems or procedures that could be used to provide the agency with more accurate schedule and financial estimates to: (1) aid in planning funding and scheduling requirements for the remedial program and (2) better forecast phasing of assignments and future resource requirements for both contractor and agency personnel.

Another expert system is the Work Assignment/Work Plan Memo (WA/WPM) generator which automates one of the more routine, but time-consuming steps in the startup of site investigation activities. The output of the WA/WPM system is a draft word processing document including a cover sheet with administrative information, descriptions of core and optional tasks required and a level-of-effort matrix of each task divided into four job categories, ODCs and travel and expense categories. The system also will optionally generate a Work Plan Memo consisting of a cover letter and confidentiality letters to be signed by key Work Assignment personnel. The system requires three types of data to be input including administrative information, data from the Hazard Ranking System worksheets and a series of site-specific questions.

A CLOSER LOOK: WORK ASSIGNMENT/ WORK PLAN MEMO EXPERT SYSTEM

The Work Assignment/Work Plan Memo (WA/WPM) generator creates two documents which are required to begin work on a hazardous waste site. These documents are the Work Assignment which is issued by the U.S. EPA and begins the process by notifying CDM to initiate the remedial planning process. CDM accepts the Work Assignment by signing and returning this document and begins drafting the Work Plan Memo. The Work Plan Memo outlines in general terms each task that will be completed during the Remedial Investigation and Feasibility Study and includes the level of effort required for each task for each of four job groups, ODCs and travel and expense estimates. Knowledge of the remedial planning process, regional and state requirements, contractor labor rates and site-specific characteristics must be known to draft the Work Plan Memo. The current manual system of drafting a Work Assignment and Work Plan Memo takes 3 weeks to 3 months and an average of 150 man-hours. The WA/ WPM expert system reduced this to 2 to 3 days and an average of 16 man-hours.

The Work Assignment/Work Plan Memo expert system reduces the time required to generate and approve the Work Plan Memo in order to begin work on a hazardous waste site. The time required for the process is reduced for several reasons. Since the expert system was developed to CDM and U.S. EPA specifications on writing Work Plan Memos, the expert system may be operated by U.S. EPA personnel with the output in a sense "preapproved" by CDM. Of course both parties must review the documents before signing, however pre-approval of the knowledgebase by both parties greatly reduces the amount of editing required. In addition, data are entered into the system in three parts; the first two data bases can be entered by support staff while the last data set contains technical questions requiring knowledge of the specific hazardous waste site. All three sections can be completed by support staff if data entry forms are filled out in advance by those people knowledgeable about the site.

This system allows the technical staff to work on more unique or challenging problems.

Time savings also are realized due to the fact that the finished, edited documents reside on the CDM computer and are transportable to other word processing systems fully compatible with the CDM system. This allows documents to be transferred between machines and sent to other users electronically, with the traditional paper mail system reserved for final versions requiring signatures.

Where a selected task or the hours required appear to be inappropriate, we can determine why and update the knowledge base by changing or adding a rule or modifying the standard hours required. This flexibility is particularly important for a system which is dependent on changes in regulations or laws. These changes become implemented immediately for all users of the system. In this manner, the expert system learns incrementally much like a human expert does. The difference is that the system is storing the knowledge of many experts and, unlike a group of experts, the system must learn a new rule only once; each expert must learn a rule for himself.

The development cycle of the WA/WPM was approximately 6 months from the time the problem was defined to the development and testing of the research prototype. However, there is no one approach to developing an expert system. The steps in the development of the Work Plan Memo Generator described below did not simply follow one another; there was a constant re-evaluation of each component as the project progressed:

- Selection of an appropriate problem is the most critical step in ensuring the success of a project—The WA/WPM project was seen as a simple application with a high payoff in terms of time savings at the beginning of the remedial process.
- Problem familiarization and scheduling—This step included general research to obtain a basic understanding of the problem domain. The goal here was not to become an expert in the problem domain, because doing so may bias the outcome of the knowledge engineering sessions. Project scheduling with a clear understanding of time, budget and personnel constraints will assist in project success.
- Identify the experts in the problem domain to include them in the knowledge engineering sessions—The goal was to have just enough information to stimulate discussion and look at the problem from different perspectives without being overwhelmed with different points of view. If the problem were properly defined, the heuristics or "rules of thumb" gleaned from the experts should not greatly differ from expert to expert. There were six such experts identified for the WA/WPM project. Since these individuals are expert in their fields, the demand on their time was great and therefore often difficult to schedule. Top management support played a critical role in obtaining their time.
- Problem scope determined but remained flexible—The development team occasionally evaluated the problem for appropriateness and potential for success. We were prepared to modify the scope to ensure success in a reasonable amount of time.
- Knowledge engineering sessions—There is no optimal number or length of engineering sessions. Three sessions were held for the WA/WPM project, each lasting 1 day. Numerous less formal discussions with the experts clarified points of confusion and continue as the knowledge base is constantly evaluated.
- Formalize the problem—The basic concepts and their relations were represented within the language framework.
- Develop rules—The IF...THEN rules are developed to properly model the knowledge of the experts. The object was to create enough rules to create the prototype system which will be used in further development and refinements. The rules were coded

into the program environment; in this case, the programming system used was OPS-5.

- Prototype system created—A prototype system was developed within 1 month of the first knowledge engineering session. A prototype is usually only useful for a limited number of cases presented to it. Many of the user-interface questions were addressed in developing the prototype. A working prototype is important in justifying continued development.
- Testing—Initial testing proceeded in conjunction with the coding of rules as the knowledge base grew and became more complete. The system evolved through several levels of "prototype" systems until the system gained depth and breadth at solving problems. The testing involved the experts, end-users (including technical and non-technical personnel) and management.
- Delivery to the end-user—This step must address any final enduser issues to ensure the system will be accepted with minimal coercion. Good, concise documentation with worksheets, sam-

ples, facts and rules contained in the system all assist the user in understanding and thus finding the system a useful productivity tool.

CONCLUSION

The advantages of using expert systems in the remedial planning process have been demonstrated with the applications CDM has developed to date. By streamlining many of the tasks using expert system technology where it is most applicable, the experts can concentrate on the more complex, unique cases or problem areas. The use of expert systems based on multiple sources of knowledge can lead to a higher level of consistency and accuracy and more informed decision-making in less time or when the experts are not available. Additional benefits of expert system technology include using them as training tools for new or less technical personnel and using them for hypothesis testing to better understand the problem domain.

Coping with Data Problems While Performing Risk Assessments at Superfund Sites

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ABSTRACT

The U.S. EPA requires that a risk assessment (sometimes called an endangerment assessment, public health assessment or environmental assessment) be performed at each Superfund site. The assessments may be part of a remedial investigation/feasibility study or part of an enforcement action. The purpose of these assessments is to evaluate all relevant site-related data and determine the potential risk to human health and the environment from site releases. PRC has performed risk assessments for the U.S. EPA at several Superfund sites throughout the country.

This paper describes some of the problems encountered in preparing assessments, focusing on those problems associated with site and supporting data. Specific problems include evaluating site data for quantity or quality, addressing variability in available data, identifying major site contaminants, obtaining media-specific data on contaminant fate and transport and contaminant toxicology, obtaining information or concentrations and determining which procedures to use to characterize risk from site releases. The paper describes how these problems were addressed and solved.

INTRODUCTION

A risk assessment is a tool used to estimate the probability of harm to a receptor from exposure to toxic agents. The U.S. EPA has recognized the importance of risk assessment and risk management in environmental regulatory decisions ¹. The agency has published in the Federal Register a series of proposed guidelines to be used in assessing various types of risks, such as carcinogenic, mutagenic, developmental and systemic risks and risks from chemical mixtures ^{2,3,4,5,6}.

In CERCLA, Congress requires that the U.S. EPA assess risks at hazardous waste sites. Specifically, Section 106(a) of CERCLA states that "... when the President determines that there may be an imminent and substantial endangerment to public health or welfare or the environment because of an actual or threatened release of a hazardous substance from a facility, he may...secure such relief as may be necessary to abate such danger and threat." The risk assessment* aids in determining whether a release from a site poses an imminent and substantial endangerment. The risk assessment evaluates the actual or potential releases from the site and estimates the impact of those releases. The U.S. EPA then uses the assessment results, along with other information, to decide whether relief is required at the site. Risk assessments also are used to evaluate any remedial action proposed for a site; specifically, whether remedial actions will mitigate any of the risks posed by site releases.

PRC has performed risk assessments at numerous hazardous waste sites throughout the country to fulfill the U.S. EPA's mandate under CERCLA. Each site was unique and had its own set of problems; however, certain types of problems occurred at many of the sites. This paper presents several of the general and sitespecific problems encountered and discusses how these situations were addressed.

The risk assessment process includes seven major steps:

- Reviewing existing data
- Identifying major contaminants
- · Determining contaminant fate and transport
- Identifying exposed populations
- Estimating exposure doses or concentrations
- Reviewing contaminant toxicity
- · Characterizing the risk associated with exposure

These steps, along with problems that have been encountered and the methods used to solve those problems, are discussed in the following sections.

Reviewing Existing Data

The most important input to any risk assessment is the data used to characterize site releases. Therefore, it is necessary to obtain as much data as possible relating to contaminant releases from a site. The data available for a specific site can pose problems in terms of quantity, quality and variability.

The quantity of available data may pose the first problem. In conducting risk assessments, there have been instances when the only data available were one set of data from one sampling effort. In some cases these data did not identify the extent of the contamination of the site but only determined whether contamination was present. Also, since the set of data was for one sampling effort only, the assessment team could not determine whether the contaminant concentrations were increasing, decreasing or remaining constant and whether they varied seasonally. In instances such as these, the data cannot be manipulated; however, if the data are of good quality they may be of value. To use such data in a risk assessment one must be aware of their limitations.

Where very large amounts of data exist, the data can be screened to eliminate duplicate or incomplete information. The most useful data are those which are from consistent sampling locations over a long period of time. Computerized databases greatly assist in manipulating large numbers of data points. At one site, over 16 years of daily or weekly data existed for one contaminant of concern at two key locations. After entering all these data into a database, we could readily calculate monthly and annual averages and draw graphs of variations within years and between years. From this analysis, we could easily evaluate the data and predict the degree of contamination.

Major problems that influence the quality of the data are encountered routinely, especially at a site that has been studied for a long period of time. Various groups may have sampled the site with no specific long-term objectives. In this situation, samples often were taken just to "see what was there." To evaluate such data, as much information as possible should be obtained regarding sampling, sample handling and analytical procedures. At a site in Indiana, large differences existed in analytical results for heavy metals from groundwater monitoring samples taken by two different groups. By obtaining information on sampling procedures, the assessment team eventually determined that one group did not filter or preserve their samples in the field, but did filter and preserve the samples in the laboratory. As a result, the heavy metals precipitated out of solution and were removed before analysis. Since heavy metals were the contaminants of concern at this site, the data generated by this group did not accurately represent site conditions and could not be used.

The analytical techniques used also present problems when various groups study a site. This is especially true if the data are from several different laboratories. It is important to determine the analytical techniques used and the quality assurance/quality control (QA/QC) procedures used. However, this can be difficult. PRC evaluated a site in California with over 40 years of analytical data available. No QA/QC information was available on the earlier data; however, there were several ways to evaluate the data. First the earlier data from the background areas were compared to the present day background data obtained with acceptable QA/QC procedures, and they were found to be similar. Information was available on the procedures used to analyze the samples. An evaluation of the analytical procedures did not indicate any of the major constituents found at this site that may have influenced the results. Based on these evaluations, it was decided to use these data in the site evaluation.

If QA/QC procedures cannot be verified, then the data may only be of limited value. In addition, when sample analyses are not conducted by a reliable source such as a federal or state laboratory or an industrial laboratory with a long record of excellence, the risk assessment based on these data may be limited to a qualitative assessment only.

Variability in data also may present problems. This variability especially occurs with groundwater monitoring results from landfills. Several procedures may be used to evaluate analytical results. First, it is usually helpful to evaluate the contamination levels in a specific well over time and determine whether there is a trend of increasing or decreasing contamination. Statistical tests, such as regression or time series analysis, may be applied to these data; however, PRC has found that, in most situations, available data are insufficient for detailed statistical analysis. Another helpful technique is to determine contaminant concentration isopleths that aid in visually presenting the data. A series of contaminant isopleth figures may be used to show if contamination concentrations have changed over time. They also may be used to show the extent of contamination and the direction of contaminant migration.

When groundwater monitoring data are evaluated, it is important to know whether the wells monitored the same aquifer at the same approximate depth. At a site in New Jersey, groundwater wells monitored three distinct geologic units. The approach used in this case was to group results from each geologic unit and compare the upgradient results to the downgradient results within each unit to determine whether a significant increase had occurred. The sample results of each unit were compared to determine whether contaminants found at the site had migrated to the lower units.

Identifying Major Contaminants

The number of contaminants identified at a Superfund site can vary widely—a site in New Jersey had over 100 contaminants, while a site in Delaware had less than 30. However, in both situations it was not feasible to evaluate the potential risk from exposure to all the contaminants. The question is how to identify the major contaminants at the site.

The Superfund Health Assessment Manual ⁷ contains procedures to identify the major contaminants (indicator chemicals) at a site. This procedure uses a formula to obtain an indicator score for each contaminant. The formula is determined by multiplying the contaminant concentration by the toxicity constant for that contaminant (the constant is media-specific and is given in the manual). PRC's assessment team calculates these scores for maximum and mean concentrations found at the site. The team does not, however, use these scores alone to identify the major contaminants. After the scores are obtained, a group is assembled to review the indicator scores. The group may consist of a chemist, toxicologist, environmental scientist, public health scientist, geologist and hydrologist. This group reviews the indicator scores for the site contaminants and other site data. The group looks specifically at site data to determine if outlying data points may have unrealistically influenced the scores. It also evaluates the changes in a contaminant's concentrations over time and whether the contaminant has been identified in many samples or only in occasional samples. It also is important to compare a contaminant's score in each medium, looking for those contaminants that scored high in all media.

The fate and transport characteristics of the contaminants also are considered, specifically, whether they will migrate or persist in the media at the site. Contaminants of similar structure are grouped together, with the objective of using one of the compounds to represent the entire class of compounds. For example, trichloroethene may be used to represent other chlorinated ethenes.

The group also will review the site history to determine whether the contaminants identified actually originated from the site. Take, for instance, a site in Ohio located adjacent to a strip mine. During the risk assessment, the PRC assessment team had to consider the influence of acid drainage from the mine when identifying the major contaminants from the site.

The team identifies the final list of major contaminants based on the above evaluations. No strict protocol is used; instead, we rely on the experience and professional judgment of team members. The total number of major contaminants identified usually varies between 5 and 10.

Determining Contaminant Fate and Transport

Once the pertinent-to-site contamination data have been evaluated and the major site contaminants have been identified, the next step is to review the available data on the environmental fate and transport properties of the major contaminants. One of the major problems encountered is that specific site information describing a contaminant's behavior relative to actual conditions rarely is available. In these cases, one must rely on literature information concerning the behavior of a specific constituent in a generic context. For many chemicals, only limited information is available concerning their behavior in the environment. It is then up to the professional to interpret this information and predict the behavior of a contaminant at the site.

Often information is available which describes the behavior of a structurally related chemical in conditions similar to those at the site. For example, at one site a contaminant of concern was 1,1-dichloroethene; the major transport medium was groundwater. Although hydrolysis is a process that may impact the fate of 1,1-dichloroethene, no information specific to 1,1-dichloroethene was found on this process. Instead, information was reviewed on the hydrolysis of two other chlorinated ethenes compounds-trichloroethene and tetrachloroethene. Because of the similar structures of the three, PRC inferred that 1,1-dichloroethene may behave in a fashion similar to trichloroethene and tetrachloroethene and have a comparable half-life in water. The same type of procedure has been used for other processes such as photolysis, oxidation, volatilization, sorption, bioaccumulation, biotransformation and biodegradation.

Some of the properties that influence a contaminant's fate and transport can be estimated. Handbooks, such as Lyman and Reehl and Rosenblatt⁸, which contain procedures to estimate such properties as octanol/water partition coefficient, solubility, bioconcentration factors, rate of hydrolysis, rate of biodegradation, volatilization from water or soil and atmospheric residence time, are available. For an assessment of a New Jersey site, PRC estimated the bioaccumulation of PCBs in aquatic organisms based on water concentration. This information then was used to estimate potential exposure to populations consuming these aquatic organisms.

Identifying Exposed Populations

To assess the risk from a site release, one must identify the human and environmental populations that may be exposed to such a release. One process which consists of several steps has been used to successfully identify those populations. The first step is to develop exposure scenarios. The exposure scenarios identify the mechanisms of exposure (such as ingestion of groundwater or inhalation of dusts) and identify specific populations exposed (such as those using groundwater as a drinking water source or children playing in contaminated soils). The scenarios rely on information regarding the contaminant's extent, fate and transport properties and area populations. The exposure scenarios should be developed around the major contaminant migration pathways and sources, such as groundwater, surface water, soils, sediment and air. Since these scenarios should be as realistic as possible, site visits are extremely helpful. If the assessment team does not visit the site, unrealistic scenarios may be developed and others may be completely overlooked.

Once the scenarios are developed, the next step is to describe the populations that may be exposed. In many instances, problems arise in attempting to quantify these populations. Information on human populations can be obtained from census surveys. In addition, local public health agencies may be excellent sources of information. At an Indiana site, the assessment team was concerned whether homes downgradient from a leaking surface impoundment used groundwater as a drinking water source. To address this concern, the team first checked local registers of groundwater wells. However, due to the imprecise nature of those records and the age of some of the potentially impacted homes, it was possible that the register information was not current. Next, the local water utility was contacted. They compared the addresses of the potentially impacted homes to their list of customers. The list of homes obtained from the water utility was then cross-checked with a city directory to verify addresses. Those homes not identified as being serviced by the utility were visited to confirm their use of groundwater.

Problems occur when attempting to describe exposed environmental populations. At most Superfund sites, there has been no sampling to quantify either the aquatic or terrestrial populations. At several sites, the only data available on local populations have been obtained from studies where the objective was to determine whether tissues of organisms found near the site contained significant concentrations of contaminants. These data can be used qualitatively to characterize local populations.

Another way to obtain information about environmental populations is to contact state and federal agencies, such as the Departments of Fish and Wildlife, Conservation or Natural Resources, to obtain any biological survey information on the general site area. If the information is not available, these agencies may have publications which describe the major regional or state habitats and the species common to those habitats. In addition, general literature may contain this type of information.

Estimating Exposure Doses or Concentrations

Once exposed populations have been identified, the next step is to estimate the exposure doses (or concentration) and the exposure frequencies. Estimation of exposure doses may be the most straightforward aspect of the exposure assessment; it also can be the most difficult. For example, at a site in Connecticut, analytical results from residential wells adjacent to the site were used to determine exposure from ingestion of contaminated groundwater. If aquatic organisms are the exposed population, surface water concentrations have been used to determine the extent of exposure.

In other cases, a mathematical model can be used to predict the concentration. Using such a model, however, is the exception rather than the rule. Most models, such as groundwater flow models or air dispersion models, require a minimum amount of data before they can be used. A groundwater flow model may require information on flow direction and velocity, porosity and permeability of the bedrock and pump test data. An air dispersion model used to estimate releases from a surface impoundment may require information on the contaminants' physical/chemical parameters such as vapor pressure, Henry's law constant, solubility, liquid phase mass transfer coefficient and gas phase and liquid phase exchange coefficient. Also required would be data on wind speed, temperature, surface area and depth of the surface impoundment and flow velocity. In most instances, there is insufficient information available to support even a simple model; this is especially true with groundwater contaminants.

Air releases from surface impoundments are more likely candidates for modeling because the data required usually are available or can be estimated. PRC has modeled releases from surface impoundments in Texas and New Jersey using a combination of several models^{9,10,11}. The approach used to estimate releases was to treat the surface impoundment as a point source and determine the emission rate of contaminants to the atmosphere^{9,10}. This emission rate was then applied to another model to calculate pollutant concentrations downwind of the source¹¹.

Another problem encountered is the contaminant concentrations to use in estimating exposure doses for each medium. PRC has used both maximum and average contaminant concentrations found at the site to establish the "worst case conditions" and "realistic case conditions." The worst case conditions is based on the highest concentrations found at the site in the medium of concern, while the realistic case condition is based on mean concentrations. By developing both exposure estimates, a better understanding is gained of the spectrum of possible exposures.

The average and maximum contaminant concentrations at the site usually are determined during the review of existing site data and are used to identify the major contaminants. Usually the data from each sampling point are entered into a personal computer using a spread sheet format. These data are manipulated to determine the maximum and mean concentrations for each contaminant identified and in each medium of concern at the site. To aid in evaluating these data, it is helpful to indicate the frequency of detection for each contaminant. This frequency of occurrence gives the risk manager a better understanding of the site data and how to weigh the "worst case" versus "realistic case" conditions.

Reviewing Contaminant Toxicity

The previous steps in the risk assessment process identified the site's major contaminants, their fate and transport properties, exposure scenarios and estimates of exposure doses or concentrations. The next step is to review available data on the toxicity of the major contaminants, focusing on the exposure routes expected at the site. As was the case with the fate and transport information, site-specific information on the toxicity of a contaminant, such as epidemiology studies, usually is not available. The accepted practice is to use data from toxicity studies that have similar exposure routes-ingestion, inhalation or direct contact. In cases where information is not available for a specific exposure route (such as toxicity via ingestion), it may be possible to use information for other routes (such as' toxicity via inhalation). However, an understanding of the behavior of the chemical in a biological system is required to draw conclusions from one exposure route and apply them to another. In making these inter-route comparisons, concern about absorption and metabolism are foremost.

Characterizing Risk

The last step in the risk assessment is to assemble all the data to characterize the risk associated with releases from the site. One of the major problems with this step is deciding whether the risk characterization should be quantitative or qualitative. The ability to perform quantitative analysis depends on the quality and quantity of the available data and whether any required assumptions are reasonable. No hard and fast rule has been developed to resolve this issue; professional judgment must be applied. For example, one may not want to calculate a carcinogenic risk estimate based on one set of data taken at a site 3 years ago, as occurred with a site in Texas. Rather than perform such a calculation, it may be appropriate to qualitatively assess the risk by comparing the data to U.S. EPA standards, criteria or guidelines, such as maximum concentration limits in the Safe Drinking Water Act, ambient water quality criteria or Health Advisories (formerly known as Suggested No Adverse Response Levels-SNARLS). On the other hand, if quality data are available in sufficient quantity, then the risk can be characterized quantitatively, as was the case for a site in Florida. Several years of data were available for this site from monitoring wells located in an area that contained several drinking water wells. These data were used to calculate an estimate of the carcinogenic risk for the area represented by the monitoring wells.

The grey area occurs when the data are insufficient to predict concentrations at the point of greatest potential exposure, but are available for an area where exposure is limited or may occur in the future. In many instances, PRC has chosen to assume that exposure will occur in the future and estimate the potential risk to future populations.

Evaluation of risk to aquatic communities usually is limited to a qualitative assessment. A common practice is to compare surface water concentrations to the U.S. EPA's ambient water quality criteria. At present, we have not attempted to determine the impact of contaminants on the entire ecosystem because limited amounts of biological, chemical and physical data are available on the specific ecosystem impacted by releases from a site.

CONCLUSION

In summary, risk assessment is a tool used to estimate the probability of harm to a receptor from exposure to toxic agents. CERCLA mandates that the U.S. EPA perform a risk assessment at each Superfund site. The agency uses these assessments and other information to effectively manage the risks posed by a Superfund site.

PRC has performed risk assessments at numerous hazardous waste sites throughout the country to support U.S. EPA. Although each site was unique and had its own set of problems, certain types of problems occurred at many of the sites. These problems included: evaluating data for quantity, quality and variability; identifying major contaminants; obtaining data on contaminant fate and transport properties; determining toxicological properties; identifying exposed populations; estimating exposure; and characterizing risk.

This paper has presented various methods that have been used to solve some of these problems. In most instances, research beyond the initial set of information was required. Professional expertise and judgment also played a role in solving these problems. The procedures presented may be only some of the ways to solve these problems.

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Educational Needs for Hazardous Waste Site Investigations: Technology Transfer in Geophysics and Geostatistics

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ABSTRACT

The multi-disciplinarity of the science of hazardous waste site investigation is placing an enormous demand on the site investigator who must be knowledgeable of the rapidly increasing gamut of highly technical procedures being developed to meet the investigative needs of the field. This paper identifies the problems of technology transfer and views it as a three-stage process involving the technological procedures, the technology transfer mechanisms and the site investigator. The three components are analyzed, requirements specified and possible solutions suggested to improve the process.

INTRODUCTION

Hazardous waste site (HWS) investigation is emerging rapidly as a new multi-disciplinary science. Advancements are being made by experts in many fields that contribute to the science. These advancements, many in the areas of geophysics, statistics, geochemistry and geohydrology, have the potential to aid the site investigator in assessing the contamination at a site accurately and cost-effectively. Several problems exist, however, that have slowed the technology transfer from the experts who have developed the advancements to the site investigator who needs the technology.

The magnitude and complexity of the contamination problem imposes demanding qualifications on the site investigator. This in turn suggests the need for a systematic program that facilitates the technology transfer by making demands on the technology itself, the technology transfer mechanisms and the site investigators. The experts must develop generally applicable procedures that solve real problems. Furthermore, the procedures must be proven, documented and easily used by non-experts.

The software and hardware must be readily available along with readable documentation and procedures manuals. The site investigator must be made aware of this technology, and the mechanism must exist to acquire the information. Finally, provisions must be made to remove educational deficiencies that might exist because of widely varying formal educations. This paper uses examples from geophysics and geostatistics and draws from the experience of the authors in presenting short courses to describe the problems and techniques of technology transfer.

THE PROBLEM

Hazardous waste sites have posed a completely new set of problems to the technical world. The problems are difficult because most of the contamination is below the surface of the earth. The classical method of obtaining information is to drill a monitoring well, collect groundwater samples and analyze the samples in the laboratory. Monitoring wells, however, are expensive to drill and maintain, are expensive and time-consuming to sample and sometimes are destructive to the surface and subsurface. Proper placing of the wells is difficult to assess, and obtaining enough wells for statistical analysis is prohibitively expensive.

The magnitude and extent of the hazardous waste problem has forced us to consider alternative methods of obtaining subsurface information. These methods, involving geophysical or soil gas techniques, have some advantages over monitoring wells, but, as in any new application of technology, they must be well understood, proven and documented before they are of general use. Finally, the information gained from the geologist, hydrologist, chemist and geophysicist (the "experts") must be consolidated to give a meaningful representation of the data. This representation often is cast as a contour map showing isopleths of contamination level. The problem the investigator now faces is to make the "BEST" map. This is the domain of geostatistics.

Geostatistics must provide not only the best map, but also a second map that estimates the errors in the map of the contaminant's estimations. In some cases, geostatistics can give valuable information about the spatial correlation of the contamination and, hence, about how the data should be or should have been taken. Highly sophisticated techniques are being developed to meet the problems of HWS, but the questions remain, how does the site investigator know of their existence, whether they are applicable or how to use them?

In this paper, geophysics and geostatistics will be used to explore the problems and possible solutions associated with the above questions. One of the authors spent a year on the road presenting a short course on Geophysical Investigations of Hazardous Waste Sites¹ which included geostatistics as a topic. The participants were mostly state and U.S. EPA personnel, with another course given for contractors. Some of the observations made while teaching these courses: (1) most of the participants had no concept of what geophysics does or how it works, and many considered it akin to water witching with a forked stick; (2) a large percentage of the participants lacked the background necessary to understand the subject; (3) under the circumstances, a short course is entirely inadequate to do more than give the participants had not even heard of geostatistics.

In the case of geophysics and geostatistics, it is not difficult to

see where the problems lie. Geophysics is a multi-disciplinary field that draws on physics and geology. In short, it uses sophisticated remote sensing probes to extract information about the subsurface. The data obtained from these probes are subject to interpretation and often must undergo complicated data processing and modeling² to extract the desired information. These techniques, developed and used by experts, are rarely, if ever, documented such that a non-expert could learn them; they are developed principally by and for the mining and petroleum industries. Comparable techniques are being developed by the U.S. EPA for use at HWSs, but so far the same problem exists. Only the experts, few in number, have the technical know-how.

Geostatistics, or spatial statistics, is being researched and developed for the Environmental Monitoring Systems Laboratory, Las Vegas by top researchers in the field.³ Developments are being made in understanding the applications to HWS and special algorithms (for example, soft kriging, indicator kriging and probability kriging) are being developed. The technology has been developed and is being tested at HWS, but again, the site investigator does not have easy access to sufficient information.

SUGGESTED SOLUTIONS

The solution to the technology transfer problem can be approached by considering the problem in three stages: (1) the technology itself, (2) technology transfer devices and (3) the site investigator.

Technology

To justify technology transfer, there must be conditions set for the technology. First, it must prove that it solves a definable problem (i.e., it must be clearly capable of solving a real problem). For example, geophysics has been used to map conductive groundwater contamination using the Electromagnetic Induction (EMI) technique. Before the technique is accepted, it must be definable and it must prove under which conditions it can solve that problem.

Next, the technique must be reduced to a defined procedure or set of procedures. In an Electromagnetic Induction (EMI) study, this means defining data acquisition, data processing and interpretation procedures that are self-consistent and that provide internal and external checks to guide the investigative process. This does not mean that a technique must be perfunctory or mechanical. The key aspects of remote sensing are interpretive and probably never will be relegated to the "black box" concept. It means that the process must make sense physically with respect to the real world (external control) and it must be internally consistent. An example of internal consistency in EMI is that the modeling process requires statistical methods to make the output valid. If the input is correct, the statistical output of the modeling provides an internal check to tell if the mechanics of the modeling process are working.

The procedure must be definable in terms understandable by the site investigator, and the technique must be demonstrably cost effective. In the case of geophysics, the quality of the results obtained by an EMI survey must justify the cost of the investigation.

The final requirement to implement technology transfer is ready accessibility of the necessary hardware and software. It serves no practical purpose to suggest to the hazardous waste site investigator a procedure that is proprietary or that is not generally applicable. When the procedure is proven and completely developed, it must be packaged before the transfer process is initiated so that it can be used by a site investigator.

Technology Transfer Devices

The next problem involves the mechanism for getting the infor-

mation from the technological experts to the site investigator. We discuss: (1) procedures manuals; (2) short courses; (3) video tapes, computer tutorials and expert systems; and (4) on the job training/consultation.

Of greatest general value is a well-written documentation of the entire procedure, which we refer to as a procedures manual. The procedures manual is a complete reference document for an investigative technique. It should contain enough theory to give the site investigator an understanding of why the procedure is valid; it also must tell in detail how to proceed from field-to-finish. Again it must be emphasized that this does not mean that there is no room for decision or inclusion of supplementary information. The most successful investigation usually will be the one that incorporates results of several techniques into the final interpretation.

The concept of a procedures manual is not new, but the paucity of them is clearly evident if one attempts to learn about a new technique. For example, there are several textbooks on the theory of geophysical prospecting from which the adequately educated can gain an understanding of the principles of the techniques. Although it is necessary for the expert to have this understanding, it does not mean he or she can apply that information to the real problem.

A real problem (for example, shallow electrically conductive contamination) has its own set of problems that must be studied and solved. Many facets of such an investigation are gained by experience, and an efficient operation must be developed. This type of information seldom exists in a useable form.

Data processing of geophysical data is standard procedure, but it requires an expert to determine which procedures are applicable to the hazardous waste site investigation, and it requires considerable time and effort to develop the capabilities in-house. Inverse Modeling,* the heart of geo-electrical sounding interpretation, is necessary to interpret data from EMI and resistivity measurements to obtain the subsurface structure. This procedure, a computerized modeling technique used by professional geophysicists but understood by very few, is, to the authors' knowledge, not documented in an understandable form anywhere. In this case, a manual describing some theory, the basic procedure and the input requirements as well as explaining the statistical output would benefit the site investigator and the professional geophysicist. This type of document is the first step in bringing technology to the user. In each case where a technical procedure has been identified, developed, tested and proven useful, such a document must be produced as the first step in the technology transfer.

A computerized procedure such as Inverse Modeling is an interactive procedure. This will be the case for any geoscience interpretive procedure. Decisions will need to be made throughout the procedure; in general, the greater the supplementary information and experience of the interpreter, the better the interpretation. It is suggested that the procedure be explained to facilitate appropriate decisions made with the most information possible. For example, the computer inverse model requires statistical information in order to make the results valid. If that is understood, the data acquisition can be optimally planned so that the modeling has the highest chance of success. Furthermore, if the results of the statistical analysis are understood, the interpretation is further aided. This information must be combined with all other data from other sources (geochemical, hydrological, geological, etc.) to make the final interpretation. Another important aspect of procedure establishment is standardization. A procedure must be repeatable at a particular site by an independent investigator, and the procedure must be defensible in case of litigation.

Once the procedures manual has been written, there are many ways to bring that information to the user. If the document could be written to accommodate all levels of users having varying educational and experiential backgrounds, the most effective transfer mechanism would be distribution to all users. Such, however, is not the case. A conclusion from the year of presenting short courses to U.S. EPA personnel is that the only assumption that can be made about the user is that he or she has some technical background and is capable and willing to learn. To implement and enhance the technology transfer, a number of devices are available.

Short courses can effectively supplement the procedures manual. The manual should be available to the participant at least 1 month prior to the course, and time should be alloted to read and digest the manual to the extent of the participant's ability. A short course then would provide an opportunity to offer specific information and explanations, to fill minor background deficiencies and to learn more about the needs of the participants.

The instructors must have actual experience in performing the procedures and, if possible, must demonstrate the procedure from field-to-finish. If this is not possible, a video tape should provide the demonstration. Video tapes can provide illustrations of actual field operations and other facets that are difficult to express in a written document. Finally, some sort of in-class evaluation must be given to test the efficacy of the course and the level of understanding of the participant. The length of the course would depend upon the subject.

Computer tutorials and video tutorials can be used with the manual and/or short course, or separately. The benefit of these aids is well understood. Expert systems, however, play a different role. The expert system is a popular topic in the field of computing and has the potential to become a significant mechanism for technology transfer. The basic concept is not new; expert systems are essentially interactive computer programs that assist the user working through a problem by prompting him or her to provide necessary data and by applying a set of pre-programmed rules to this data to identify the best solution. What is new in expert systems is a programming methodology, developed as a result of research in "artificial intelligence." This methodology permits the rules which apply to a particular problem to be entered in a data table independent of the program which processes the rules; rules can be added, deleted or modified without extensively re-programming the system. It is, therefore, becoming more practical to computerize such things as procedures manuals, guidance documents, operating instructions, etc. The expert system must degrade gracefully when queried beyond its rules and must use feedback loops to learn new rules from previous experiences. However, the expert system is only an aid to but not a replacement for the expert. The U.S. EPA Office of Research and Development has committed funds to evaluate the application of expert systems to HWS. We can look forward to some very interesting developments in this field in the next 4 years.

Finally, again supporting the theme that HWS Investigation is an interpretive interdisciplinary science and that expert decisions must at times be made, there must be access to experts. These experts must be available either for consultation by telephone or to provide on-the-job training. An investigation should not be completed without the capability of consultation with an expert. Preferably, on-the-job training would be provided to guide the investigators trained by the above methods through the first investigation. This last step would close the loop in the transfer from expert to practitioner and would provide the opportunity for the expert to fine-tune the method to the application.

Site Investigator

Finally, a few comments must be made about the investigator. The educational backgrounds of the HWS investigators are varied and include biology, geology, hydrology, business, physics, art, etc. It is easy to see that the difficulty of implementing technical procedures will vary greatly according to the background of the investigator. This is a matter over which there is very little control; however, a reasonable approach would be to recommend appropriate university courses for those lacking the appropriate technical background. This requirement would be most feasible in locations close to a university campus. Some universities offer appropriate short courses during the summer. Another long-range solution would be to offer scholarships to students to train in specialties that are needed for HWS investigations.

CONCLUSIONS

Presently, many new technical methods have been and are being developed for HWS investigations. These methods are understood by only a few researchers, i.e., the experts, and very little if any information is shared with the site investigator charged with the responsibility of evaluating the contamination. These technical methods must be fully developed, tested and proven useful and cost-effective.

Next, the methods must be completely documented so that they can be understood and executed by the properly educated site investigator. The wide range of educational and experiential backgrounds of the investigators requires a more complete program of technology transfer including short courses, video and computer aids and the close interaction of the experts with the investigator during early stages of the learning process. The Hazardous Materials Control Research Institute has been a pioneer and pace-setter in this multi-disciplinary technical transfer by making available a forum in the annual Superfund Conferences.

DISCLAIMER

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A Collection/Treatment/Recharge/Flushing Groundwater Remediation Program

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ABSTRACT

Volatile organic compounds usually associated with spent solvent disposal were identified as the contaminants in an unconfined glacial outwash aquifer. As a result of a remedial investigation/feasibility study, a remedial action alternative was selected.

The selected alternative included a combination of groundwater collection, treatment and recharge and soil flushing. The collection system withdraws the groundwater from several levels in heavily contaminated areas. This water is diluted with water collected from a system of wells that prevents the migration of contaminants to an adjacent river. The groundwater will be treated using an induced draft air stripper. Effluent from the stripper will be spread in a recharge area located over the heavily contaminated areas. Additional treatment of volatile organics will be provided by natural volatilization as the water percolates into the ground. Prior to being recycled, recharge water will move downward through the contaminated soils flushing the residual contaminants.

Pump and pilot testing conducted prior to construction resulted in several design changes. These included an increase in the amount of groundwater treated, a change in the treatment hardware specified and a redesign of the system to distribute the treated water over the recharge area.

INTRODUCTION

A manufacturing facility is located on the lower of two peninsulas formed by a reverse "S" meander of a river (Fig. 1). In the late 1960s the local regulatory agencies granted permission to the manufacturer to use the upper peninsula as a waste disposal area. As a result of the change in the environmental regulatory atmosphere in the 1970s, a consent judgment was negotiated between the state and the manufacturer providing for the cleanup and remediation of the waste disposal area.

Fig. 2 shows the areas where the major disposal activities took place. Three paint sludge pits were located in the area of monitoring well 2 (MW-2). A cache of drums was buried just west of MW-2; drums also were placed in a ravine located in the western portion of the site north of MW-3. The central portion of the site, between MW-1 and MW-2, was the location of numerous batch spills and general disposal of solid wastes.

Site cleanup was conducted in 1981. At this time, 1500 drums were removed from the ravine, while another 1200 were removed from the cache located west of MW-2. Approximately 2700 yd³

of paint sludge and associated contaminated soils were excavated from the three paint sludge pits. In addition, 27,300 yd³ of contaminated soils were excavated from the central portion of the site and the drum areas.



Remedial Investigation

The remedial investigation was conducted in three phases. The first phase was the exploratory phase during which six well nests were installed (MW-1 to MW-6). As a result of this activity, the general site stratigraphy was defined. Five major hydrogeologic units were identified. The uppermost unit is an unconfined glacial outwash aquifer which is in communication with the river.



Figure 2 Locations of Disposal Areas

Within this unit in the western portion of the site is a lacustrine aquiclude. Remnants of this aquiclude also were found in the eastern portion of the site. Underlying this upper outwash aquifer is a substantial glacial till aquiclude followed in order by another glacial outwash aquifer, a glacial till aquiclude and a glacial outwash aquifer which was encountered in one borehole at an approximate depth of 150 ft below grade.

During the second phase of the remedial investigation, it was determined that all contamination was confined to the upper outwash aquifer and that trichloroethylene (TCE) was the dominant contaminant at the site. As a result, TCE was selected as the indicator compound used to monitor site cleanup.

A third phase was instituted to better define the stratigraphy of the central portion of the site where most of the disposal activities took place in preparation for designing the groundwater collection system. The major hydrogeologic units encountered during this third phase study were the upper outwash aquifer and the underlying upper till unit. Within the upper outwash aquifer are lenses of various combinations of fine materials which act as aquitards or aquicludes. These lenses form the aquiclude/aquitard units and are found at many levels and varying areal extents throughout the upper outwash aquifer. The majority of these units seem to be grouped at elevations of 805 and 790 ft (grade elevations range from the river elevation of 811 to 835 ft). The two identified aquiclude/aquitard layers exhibit variable hydrological characteristics. This variability is reflected by the fact that at some locations the 805 layer exists but not the 790 layer, and vice versa. At several locations, the 805 and the 790 layers are one unit, while at other locations neither exists. In addition, some locations have layers at other levels within the upper outwash aquifer which do not correlate with either the 805 or the 790 layers.

The movement of groundwater within the upper outwash aquifer is complex. Groundwater flows to the river and vertically around and through the aquiclude/aquitard layers. The upper outward aquifer was divided into the upper, middle and lower portions. The upper portion of the aquifer roughly lies between the water table (811.0 to 812.5 ft) and the 805 layer. The middle portion lies between the 805 and the 790 layers, and the lower portion lies between the 790 layer and the upper till aquiclude.

Lateral groundwater movement on the site is directed toward the river from a groundwater high located between MW-1 and MW-2. This same pattern generally is reflected in the flow patterns of the three levels. Vertical groundwater movements are upward to the river along the site boundary. Upward and downward groundwater movements have been identified at various locations and over a variety of the hydrogeologic units.

As described above, the complex nature of the site stratigraphy is responsible for the variability of the horizontal and vertical groundwater flow pattern and, thus, is the major factor determining the contaminant migration pathways. Once the stratigraphy was well defined, the design of a groundwater collection system became a relatively straightforward task.

Feasibility Study

The feasibility study was a relatively straightforward procedure because of the limited options available for consideration. The groundwater had to be collected, treated and discharged. The options for collection included number of wells, depth of wells and the amount to be pumped. Pump tests were needed before the proper selection could be made. Air stripping was selected as the treatment process due to its recognized lower capital, operation and maintenance costs. Discharge to the adjacent river was the obvious solution, but it was decided to put the treated discharge to work by recharging the discharge in the area where most of the disposal activity took place. Recharge and the recycling of the water would act to flush the residual contaminants from the soils.

Once these basic decisions were made, a pilot study was instituted to better define and determine the feasibility of the selected alternatives. Pump tests were conducted to help define the collection system. In addition, pilot treatment and recharge tests were conducted.

COLLECTION

Pumping tests were conducted in five pumping wells at three locations and at two depths. The pumping well locations are designated PW-1 to PW-3 on Figure 2. The two depths coincided with the upper and middle portion of the upper outwash aquifer. Contamination within these two portions of the aquifer was documented during the third phase of the remedial investigation. Location PW-1 was chosen because it was representative of the central spill area. PW-2 was chosen to be within the identified contamination plume extending from the waste disposal area to the river, and PW-3 was chosen to represent conditions in the paint sludge pit area.

All pump tests were 48 hr long; a minimum of 4 and a maximum of 6 observation wells were monitored during each test. Observation wells screened at depths other than the pumping depth were included in the group of wells monitored for each test. These wells were included so that the effect of pumping on other portions of the aquifer could be evaluated. A summary of the pump testing results is presented in Table 1.

TREATMENT

The major contaminant identified in the groundwater through the above mentioned remedial investigation is trichloroethylene (TCE). Based on the physical and chemical properties of this volatile organic compound, the two treatment processes suitable for its removal from water are air stripping and carbon adsorption. Although these two treatment processes are both feasible and dependable, air stripping was selected due to its recognized lower capital, operation and maintenance costs.

Having selected the type of treatment process applicable, the next phase was to determine the optimum engineering parameters for design. Accordingly, treatability studies were planned and executed. An induced draft air stripper equipped with nozzles having an air-to-water ratio of 575 was used for the treatability study. While the air-to-water ratio remained constant during each experimental run, the environmental air temperature did vary. Temperature variation is expected during the actual treatment operation.

The objective of the treatability study was to obtain design data by simulating the actual treatment process. Accordingly, all experiments were conducted with full-scale equipment using the contaminated groundwater at the site. For the induced draft stripper, the objectives were to determine the removal efficiency and the number of strippers needed to attain a treatment level less than or equal to $15 \mu g/L$ of TCE. Another objective was to determine the number of passes required to achieve the treatment level using only a single induced draft stripper.

Fig. 3 depicts the field experimental setup. First, groundwater at a temperature of 55 °F was pumped to fill the lower reservoir (Tank #1, approximately 500 gal). The groundwater then was pumped up to the stripper, circumventing the nozzles, and allowed to gravity flow to the upper reservoir (Tank #2, approximately 500 gal) and then to the lower reservoir where it was recycled back to the stripper. This was done for about 10 min to equilibrate the system. After equilibration when the lower reservoir was filled, two samples were taken and measured for TCE concentration. The average TCE level in the two samples was designated as the initial concentration, or Co. The water in the lower reservoir was then pumped (40-50 gal/min) through the stripper nozzles, and the effluent was collected in the upper reservoir. After all the water had passed through the stripper and into the upper reservoir, two samples were taken for analysis from a sampling bibb. The average level in the two samples was designated as effluent concentration, or Ce. The removal efficiency was calculated as follows:

% removal efficiency =
$$\frac{\text{Co-Ce}}{\text{Co}} \times 100$$
 (1)

The above procedure was repeated for the number of times required to achieve the treatment level.

RESULTS

Fig. 4 depicts typical results of the stripping action system. The concentrations as a function of the number of passes through the stripper are plotted. These results indicate that almost all the TCE in the water can be removed. However, to achieve the near zero effluent concentration, five passes through one stripper or one pass through five strippers in series are required. Fig. 5 shows the cumulative removal efficiency versus number of passes. As previously indicated, this type of plot can be used to determine number of passes required to achieve a desired removal. As was verified in the field, higher TCE levels (greater than 400 μ g/L) would require greater number of passes to achieve a near zero concentration level. The reverse is true for lower concentrations.

Table 1 Pumping Characteristics

Well	Treasmissivity (gal/day. ft)	Storativity (unitiess)	Local Boundary Condition	Local Aquifer Type
PW-1A*	22900	0.0045	Impermentie	vacoafiard
PW-18*	12400	0.000015	recharge	leaky confined
PW-2B	34500	0.00005	impermenble	unconfined
PW-3A	15900	0.032	recharge	unconfined
PW-38	10100	0.00047	recharge	leaky confined

*The suffix "A" denotes a pumping well screened in the upper portion of the aquifer and "B" denotes a pumping well screened in the middle portion of the aquifer.



1 All piping and valves - 2" except 1/2" air and vacuum, and 1/2" sampling bibb (Meter 2")

- 2 Process pump 50 gpm at 55 psi(min).
- 3 Gravity flow from: air stripper to Tank #2, and Tank #2 to Tank #1,

Figure 3

4 DC Gate or ball valve (depending on cost).



Figure 4 Effluent TCE Concentration as a Function of the Number of Passes

RECHARGE

A 20- by 40-ft pilot recharge area was constructed on-site. The area was excavated, leveled, filled with pea gravel to a depth of approximately 1.0 to 1.5 ft and bermed. The gravel was used to provide greater distribution of the treated water and to provide additional air/water contact before the water infiltrated into the ground.

Several methods were used to distribute the treated groundwater on the gravel bed. These methods ranged from using perforated flexible field tile to using a rigid system constructed of



Cumulative Removal Efficiency as a Function of the Number of Passes

PVC pipe equipped with spray nozzles. The latter method proved to be the most effective, both in terms of efficiency and cost. Fig. 6 shows both a plot plan and a cross-section of the pilot recharge area using the spray distribution system. In constructing the spray distribution system, the gravel bed provided direct structural support. The spray nozzles were directed upward to provide optimal distribution of the treated water over the recharge bed and to optimize residence time for additional air stripping of the TCE. This additional air stripping removal efficiency was 94% at an ambient temperature of 77 °F (Table 2). Removal of 79% of the influent TCE was achieved between the time the water left the nozzles and the time it came in contact with the gravel bed. Another 15% removal was achieved as the water traveled through the gravel bed.

 Table 2

 TCE Removal in Groundwater Distribution/Recharge System

	Influent to Distribution System	Influent to Gravel Bed	Effluent from Gravel Bed
Average TCE Concentration (ug/L)	98.50	21.00	6.00
95 Percent Confidence Limits (ug/L)	3.79	5.51	2.48
Removal Efficiency (%)		78.7	15.2
		Overall Removal	Efficiency: 93.9%

FLUSHING

Due to the complex nature of residual soil contamination, no pilot studies were conducted addressing the flushing of the contaminants from the soils. The flushing of contaminants from the soils will be a direct result of a combination of treated ground-



Figure 6 Pilot Recharge System

water recharge and groundwater collection. The groundwater collection system will facilitate the movement of the treated water through the contaminated soils. The effectiveness of this remediation system will be evaluated by monitoring the TCE concentrations of influents from wells in key areas over time.

CONCLUSIONS

The results of the remedial investigation and feasibility study indicated that the remedial program being evaluated is feasible. However, the complex nature of the disposal area stratigraphy will require a larger number of collection wells than originally estimated. These wells will be placed at two levels. The collection system will be designed to collect contaminated groundwater and prevent its migration to the adjacent river. The system also will provide a flushing mechanism for the soils. It is estimated that a combined pumping rate of 600 gal/min would be optimal for the system.

The study also indicated that the desired level of TCE removal can be achieved using a series of induced draft air strippers or a combination of the tested induced draft air stripper with the distribution and recharge system. Since the expected flow to the treatment plant is much higher than the previously anticipated flow (600 gal/min compared to 30-60 gal/min), 12 air strippers of the type used in the pilot study would be required to treat the expected flow. A re-evaluation of the proposed use of the induced draft air stripper is warranted because of the large number of strippers needed.

Finally, the pilot studies showed that the treated groundwater distribution and recharge system is very efficient and cost effective and, under certain circumstances, could stand alone as a groundwater treatment system.

Establishing and Meeting Groundwater Protection Goals in the Superfund Program

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ABSTRACT

A decision process for identifying, evaluating and selecting Superfund groundwater response actions is currently being developed by the Superfund Program. The process applies the Agency's Groundwater Protection Strategy and is a flexible remedy selection and re-evaluation process that allows for more effective decision-making at the Record of Decision stage. The goal of this decision process is to return usable groundwater to beneficial use within a time-frame that is reasonable given the particular circumstances of the site.

INTRODUCTION

Decisions on contaminated groundwater at uncontrolled hazardous waste sites are complicated due to complex fate and transport patterns. The process being developed will guide Remedial Project Managers (RPMs) and other decision-makers concerned with groundwater remedial actions at Superfund sites so that a consistent groundwater evaluation and decision approach is applied to all Superfund sites.

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Under the NCP,' remedial actions at Superfund sites shall meet or exceed all applicable or relevant and appropriate Federal requirements and consider other pertinent Federal criteria, advisories and guidance and state standards. (This paper was prepared prior to CERCLA reauthorization. In the event of a new statute certain aspects of the cleanup standards discussion may be altered.) The Federal requirements that may be most applicable, relevant or appropriate to Superfund groundwater actions are the RCRA Subpart F regulations. Determinations of groundwater protection levels under both RCRA and Superfund may be based on a site-specific risk assessment.

The Safe Drinking Water Act and the Clean Water Act resulted in the development of maximum concentration levels (MCLs), recommended maximum concentration limits (RMCLs), health advisories and water quality criteria for protection of public health which may be evaluated for groundwater protection levels in the Superfund program. The U.S. EPA's Groundwater Protection Strategy is an important component of Superfund's groundwater approach. The strategy says that groundwaters should be protected differentially based on characteristics of vulnerability, use and value.

Special groundwaters (Class I) are those that are highly vulnerable to contamination because of the hydrological characteristics of the areas where they occur. They are characterized by either of the following factors:

- The groundwater is irreplaceable because no reasonable alternative source of drinking water is available to substantial populations
- The groundwater is ecologically vital, by providing the base flow for a particularly sensitive ecological system that, if polluted, would destroy a unique habitat

Current use groundwaters (Class II A) and potential use groundwaters (Class II B) that are sources of drinking water (or other beneficial uses) include all non-Class I groundwaters that are currently used or are potentially available for drinking water or other beneficial use.

Groundwaters not considered potential sources of drinking water and of limited beneficial use (Class III) are non-usable groundwaters which are highly saline, i.e., they have total dissolved solids (TDS) levels over 10,000 mg/l, or are otherwise contaminated beyond levels that allow cleanup using methods reasonably employed in public water treatment systems. This condition must not be the result of a single waste site, but must be the result of a wide range of sources. Class III is further separated by the degree of inter-connection with adjacent water. Class III A groundwaters are highly to moderately inter-connected and are thus most relevant to Superfund. Class III B groundwaters have a low degree of inter-connection and are typically at greater depths.

As will be explained in this paper, the Superfund program will use these groundwater characteristics in the evaluation of alternative response actions.

DEVELOPMENT OF GROUNDWATER ALTERNATIVES

In general, source control measures should facilitate the achievement of long-term remediation objectives and goals for groundwater. The Guidance Document for Feasibility Studies Under CERCLA² calls for the development, screening and de tailed evaluation of alternatives proposed for remedial actions. For groundwater contamination problems, this process involves the development of a limited number of remediation alternatives to be presented to the decision-maker.

The performance goal of each groundwater alternative should be expressed in terms of a cleanup concentration (in the groundwater) and a time period for restoration for all locations in the area of attainment. Concentration levels may be derived from health based criteria such as excess unit carcinogenic risk (UCR) or reference dose values. These levels may be available or be derived from MCLs, RMCLs, health advisories or water quality criteria. Health based criteria also may be developed if no standards, advisories or criteria are available. The reader is referred to the Superfund Public Health Evaluation Manual' for information on developing health based criteria. Restoration time periods may range from very rapid (1 to 5 years) to relatively extended (perhaps several decades).

If Class I or II groundwaters are contaminated with known or suspected carcinogens, the program desires that a limited number of groundwater protection goals be developed that vary between 10^{-4} UCR and 10^{-7} UCR and vary between restoration time periods. A point of departure alternative for initial decision evaluation should be developed at a 10^{-6} UCR and 1- to 5-year restoration time period. For non-carcinogens, alternatives should be developed that meet chronic or acute threshold levels in varying restoration periods.

In situations where the plume is not close to a receiving body of water, plume containment measures (such as gradient control) also should be evaluated which eventually will result in a 10^{-4} UCR and 10^{-6} UCR for carcinogen levels in the groundwater. A limited number (possibly two to three) of other alternatives also should be developed around the point of departure. Fig. 1 presents a conceptual risk/restoration time plot of these suggested alternatives for carcinogens contaminating groundwaters with Class I or II characteristics.

These alternatives then will be evaluated to compare the tradeoffs between the cleanup level, time to the achieve level and cost of the action.

Performance Range for Groundwater Remedial Alternatives (General)





CONTAMINATED AQUIFER CONTROLS 225

Figure 3

Possible Restoration Scenarios When Evaluating Performance Data

DECISION ANALYSIS

Selecting and implementing a remedial action alternative depends upon many factors. Those factors relating to the concentration level for carcinogens in the groundwater are:

- · Other health risk borne by the affected population
- Population sensitivities

For example, at the Reilly Tar Superfund site, the population had been exposed to contaminated groundwater for an undeterminable period of time; this unknown exposure influenced the decision to use a "more protective" concentration level. Similarly, a more protective concentration level may be evaluated if the exposed population is unusually sensitive to the contaminants. Acute and chronic levels for non-carcinogens are threshold values and, therefore, are not influenced by these two factors.

Factors that influence the restoration time period for groundwaters contaminated with carcinogens and non-carcinogens are:

- · Feasibility of providing an alternative water supply
- Current use of groundwater
- Potential need for groundwater
- Effectiveness and reliability of institutional controls
- Ability to monitor and control the movement of contaminants in groundwater

If there are other readily available drinking water sources of sufficient quality and yield that may be used as an alternative water supply, the importance of rapid restoration of the contaminated groundwater is reduced. Where a future demand for drinking water from groundwater is likely and other potential sources are not sufficient, those remedies which achieve more rapid restoration should be favored.

The effectiveness and reliability of institutional controls to prevent the utilization of contaminated groundwater for drinking water purposes should be evaluated. If these controls are not clearly effective, rapid restoration may be necessary.

In some circumstances, complex flow patterns increase the potential for unanticipated migration pathways and may reduce the effectiveness of remedial action. Remedial actions that will rapidly restore groundwater should be emphasized in these situations.

Other factors that should be considered in determining the appropriate groundwater protection goal for carcinogens and noncarcinogens are:

- Limiting extent of contamination
- · Impact on environmental receptors
- Technical practicability of implementing the alternative
- Cost of alternative

Limited increases in concentration may be evaluated if the expanded area is relatively small, the time period of degradation is short and the ultimate discharge of the plume has no significant effect on surface waters.

The technical practicability of each alternative must also be evaluated in light of the contaminant characteristics and hydrogeological conditions which may not allow effective implementation of the alternative to clean up the groundwater.

Environmental receptors should be taken into account when evaluating the appropriate cleanup concentration levels and time period.

Finally, under the NCP, response actions must be cost-effective. Therefore, a careful evaluation of capital outlays and operation and maintenance costs associated with each alternative must be considered and compared to those of each of the other alternatives. Groundwater goals may not be met if high costs invoke fund balancing.

Fig. 2 presents general groundwater goal areas associated with



Figure 4 Flexible Decision Process for Groundwater Remedial Actions

the groundwater characteristics on the risk/restoration plot for carcinogens. The decision-maker should first evaluate the point of departure remedy and then move to other general areas on the plot as influenced by the groundwater characteristics. The reader should be cautioned that the general areas delineated on the plot are not rigid.

FLEXIBLE DECISION PROCESS

Complex fate and transport mechanisms of contaminated groundwaters often make accurate predictions of the performance of the groundwater remedial action difficult. Therefore, the remedial process must be flexible and allow changes in the remedy based on the performance of several years of operation.

To illustrate this variability in results and concomitant need for flexibility, Fig. 3 presents three possible situations that may occur after several years of a groundwater response action. In the first scenario (Case 3A), the target concentration will be reached within the desired time period; in the second scenario (Case 3B), the target concentration will be reached somewhat later than the desired time period; and in the final scenario (Case 3C), the target concentration will not be reached in a foresceable time period.

A performance feed-back concept has been incorporated into the decision process so that in situations where the performance goal will not be met (such as Case 3B and Case 3C), the decisions may be re-evaluated based on actual experience. If the implemented remedial action is not meeting expectations, the decisionmaker should decide the extent to which further or different action is necessary and appropriate to protect human health and the environment; Fig. 4 illustrates this evaluation process. Should it be impracticable to restore the groundwater to the initial cleanup goal, an exception to the NCP for meeting applicable or relevant and appropriate Federal requirements such as Fund balancing or the technical impracticability waivers could be demonstrated.

REFERENCES

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Pitfalls of Geophysics in Characterizing Underground Hazardous Waste

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ABSTRACT

Several geophysical techniques, including magnetics, electrical/ electromagnetics, seismic refraction and ground probing radar, frequently are applied to hazardous waste investigations. Depending on the nature of the problem, these techniques have been used successfully to trace groundwater contamination, locate buried drums, map the location and extent of pits and trenches and assess the general geologic setting of a site. However, many researchers find that the methods often do not work or can be misleading.

In some cases, cultural or natural "noise" or terrain conditions preclude successful surveying. However, the most important problems occur because of inexperienced operators and/ or interpretors. The main conclusion of this study is that, when properly applied by experienced personnel, geophysics is a necessary and useful tool in a hazardous waste site investigation. With a minimum amount of site information, the geophysicist usually can assess the probability of success of a given technique and define an effective program of study. Some locations are so adverse that geophysical techniques are not appropriate, but such locations can be defined in advance.

INTRODUCTION

Much of the current experience in applying geophysical techniques to hazardous waste investigations is negative. The results of the investigations often fall short of what is expected and, in some cases, can yield misleading results. Some of the problems frequently encountered include:

- Incorrect Method Applied—Possible causes include lack of understanding of geophysical technology by the planner (a non-geophysicist), or a lack of understanding of site conditions or the objectives of the survey.
- Poor Data Quality—Possible causes include high ambient noise, poor field procedures, improper use of equipment, faulty equipment, adverse geologic conditions or inexperienced operators.
- Poor Interpretation—The problem of interpretation is frequently the use of an inadequate interpretation method, having insufficient background information or insufficient or noisy data.
- Insufficient Data—Possible causes include a lack of understanding of methods and/or site conditions and objectives, operator inexperience, lack of up-to-date plotted data in the field (some contractors gather data but do not plot it or look at it until they are back in the office).

The situation is serious. One researcher' estimates that with one technique alone (DC resistivity) about 40% of the surveys for the

evaluation of groundwater contamination were not successful or obtained only limited results. This estimate may be optimistic. The experience of some organizations is so bad that the use of geophysics in a site investigation is virtually banned.

The intent of this paper is to highlight the authors' experience with problems that commonly are faced with the surface geophysical techniques most commonly employed during investigations of groundwater contamination and hazardous waste. Emphasis has been placed on defining the limitations of applying geophysics, considering factors such as cultural or natural "noise," terrain conditions, resolution and common mistakes made due to the inexperience of operators and/or interpretors. Examples are provided from real case histories where methods were not successful or where data were misinterpreted (for obvious reasons, confidentiality has been maintained). Comments are provided to highlight the pitfalls that can trap the unwary researcher.

PITFALLS OF DIFFERENT GEOPHYSICAL TECHNIQUES

The main surface geophysical techniques applied to hazardous waste and groundwater investigations include DC resistivity, electromagnetics (EM), magnetics, ground probing radar (GPR) and seismic refraction. Details of the theory and applications of these methods are beyond the scope of this presentation and the reader is referred to publications such as the book *Geophysical Techniques for Sensing Buried Wastes and Waste Migration*,² for a general introduction and the proceedings of the NWWA/U.S. EPA conferences on "Surface and Borehole Geophysical Methods in Groundwater Investigations,"^{3, 4} for more detailed information. These techniques are discussed separately.

DC Resistivity

DC resistivity is one of the most widely applied methods of engineering geophysics. The basic field and interpretive procedures have been known since the beginning of this century. Equipment is relatively inexpensive and readily deployed in the field with little operator training. This last characteristic also works to the disadvantage of the technique.

DC resistivity measurements usually are made by measuring the voltage drop between two electrodes in the ground after an electrical current has been induced in the ground between two other electrodes. The most commonly applied electrode configurations are referred to as the Wenner and the Schlumberger array. In the Wenner array, the electrodes always are separated by a constant distance called the "A" spacing. With the Schlumberger array, the voltage electrode spacing is constant while the current electrode spacing is variable.

Blectrical "soundings" obtain information on the vertical variation of electrical properties by expanding the electrode spread. Electrical profiles are obtained by moving a fixed electrode spread along a survey line in order to define lateral variation of subsurface electrical properties. Ultimately, the data are used to derive electrical models of the subsurface which can be related to the presence of contaminated plumes (dissolved contaminants frequently cause groundwater to have an abnormally low resistivity) and buried wastes.

All of the generic difficulties inherent in conducting a geophysical survey outlined in the introduction are applicable to DC resistivity. Pitfalls specific to this method are outlined as follows:

- Improper Selection of Technique—Unless ground conditions are fairly simple, the use of the Schlumberger array is nearly always preferable to the Wenner array. The Wenner array can have excessive problems due to lateral resistivity variations to which the Schlumberger array is less sensitive.
- Improper Equipment—The equipment should be capable of inducing adequate current in the ground. Low-frequency AC is preferable to pure DC.
- Difficult Terrain—The presence of a highly resistive surficial soil (e.g., dry sand, frozen ground), presence of surface conductors (e.g., fences or railroad tracks), underground metal pipes or any buried metal will cause difficulty. Meaningful resistivity results should not be expected from the top of a land-fill.
- Poor Field Procedure—Careful field notes should be made to note the proximity of electrodes to any possible source of an erroneous reading, such as a metal fence; the operator should be aware when metal electrodes are not suitable and special electrodes and/or salt water soaking of the ground is necessary; repeat measurements should be made; lateral inhomogeneities need to be recognized in the field.
- Improper Interpretation—Most of the difficulty with this technique is associated with the interpretation. Often, the interpretor did not collect the field data and is not in a position to recognize possible cultural interference in the data unless careful field notes have been made. An accepted, verified inversion program should be used to derive sections of true resistivity versus true depth. Contour maps of apparent resistivity can be highly misleading, and electrode spacing should not be considered to have a linear relationship with depth of penetration.

A few of these pitfalls are cited in the following case histories.

Case History Site 1

Site 1 is the location of two unlined ponds containing an acid fluid with chloride. Overburden forming the base and sides of the ponds consists of low permeability silts and clays. Seven resistivity soundings using a Wenner array were conducted at several locations, and an optimum "A" spacing of 35 ft was selected as the basis for several fixed-spacing measurements. The apparent resistivity at the 35-ft "A" spacing was contoured as shown on Fig.1. On this basis, it was concluded that groundwater flow in the overburden occurred predominantly in one or more thin discrete sand units interbedded with the silt and clay. Chloridecontaminated groundwater was interpreted to leak radially from the pits and preferentially toward the northwest. A second source of contamination was identified approximately 500 ft north of the ponds. Bedrock was interpreted to be present at a depth of 25 to 45 ft with a N-NW dip, occasionally with a 10-ft layer of weathered rock at the bedrock surface.

Comments: The soundings were not interpreted; i.e., true resistivity versus depth sections were not calculated. Apparent resistivity values were miscalculated so that the contoured values

should actually range between about 300 and 900 ohm-ft. This range did not justify the fine contour interval presented. The apparent resistivity values at all "A" spacings (from 5 to 80 ft) generally do not exceed this range of resistivities. Information on the depth to bedrock or bedrock weathering cannot be resolved by the sounding curves. It is not known by what basis a 35-ft "A" spacing was selected for fixed-spacing measurements, but with the clayey soils found at this site it is certain that the 35-ft "A" spacing does not represent information from a depth of 35 ft. The available data are difficult to interpret, but the variations in measured values of apparent resistivity are consistent with interbedded silt and clay with some sand lenses. The interpretation of a northwest migrating contaminant plume and the dipping bedrock surface is not substantiated by the resistivity data. Pitfalls: improper field procedures, poor interpretation and inadequate data base.





Case History Site 2

To provide preliminary data on geologic conditions at a hazardous waste landfill, a resistivity survey was conducted to provide guidance to the proposed drilling program. Specifically, the survey was designed to identify the extent of low-permeability sediments beneath a known aquifer and to provide information regarding the lower aquifer. A grid of vertical soundings was conducted around the landfill using a Wenner array with "A" spacings ranging from 10 to 120 ft. The "Keck" method was used to interpret the data. Contours representing resistivities at





Figure 3 Summary of Geoelectric Soundings from Site 3

technique, it is not necessary to plant electrodes in the ground and measurements are, therefore, quicker and easier to perform than with DC resistivity. Areas with a highly resistive surficial soil, asphalt or concrete which preclude the planting of electrodes, are readily surveyed with EM equipment. EM measurements are not as susceptible as DC resistivity to the presence of metallic interference such as fences, underground pipes or scattered metallic debris. With these advantages, many investigators apparently feel that EM methods can replace the need for DC resistivity. However, site conditions favorable to DC resistivity can severely limit the effectiveness of EM and there are other pitfalls, as outlined:

- EM measurements are highly susceptible to cultural or natural EM fields. Power lines, underground cables, transformers, etc., which tend to be present at hazardous waste sites, can severely distort the measurements. Field personnel must carefully document the position of known EM interference.
- EM surveys do not work well where the resistivity of surficial materials is low, for example where chemicals have been spilled on the surface or where clay soils are present.
- The EM method has very limited capability for defining the variation of resistivity with depth.

The above restrictions are severe. In cases where the desired result is to map a contaminated plume in a sand layer beneath a surficial clayey soil in an area of cultural interference, it probably is not worth the effort to conduct the survey. Note that many hazardous waste sites fit this description.

Case History Site 4

An EM survey was conducted to define the extent of soil and groundwater contamination around a sludge lagoon. Measurements were taken in essentially a random manner with a Geonics EM-31 (Fig. 4). The study concluded that the survey was not successful in defining the extent of contamination because insufficient contrast existed between contaminated and non-contaminated areas.

Comments: The results shown on Fig. 4 clearly show the presence of anomalously high ground conductivity along the southern border of the lagoon which gradually decreases with distance away from the lagoon (see contours added on Fig. 4). This should have been identified as a contaminant plume, as was later demonstrated on the basis of groundwater testing. The study would have benefited greatly if systematic measurements were taken along profiles or as a grid, rather than in a haphazard manner.



Figure 2 Electrical Cross-Section Through Site 2

various depth intervals were generated, and geoelectric crosssections were made indicating zones of possible clay, fine sand and sand and gravel. An example cross-section is provided on Figure 2.

Comments: As shown in the cross section, the "Keck" method generated some unrealistically high resistivities, some higher than 1,000,000 ohm-ft. Such points should have been recognized as due to noise and eliminated. The interpreted cross-section derived is not geologically realistic and implies that the "A" spacing is somehow equivalent to depth, which it is not. A more realistic and meaningful cross-section probably could have been obtained by use of a conventional inversion technique. However, the use of a resistivity survey to derive information from a horizon beneath a known aquifer implies the existence of more layers than the resistivity technique can be expected to interpret. Pitfalls: poor interpretation and improper use of technique.

Case History Site 3

To map the migration of a contaminant plume from a hazardous waste landfill, a series of geoelectrical soundings was conducted at the perimeter of the site. A detailed stratigraphic model of numerous layers was defined. The raw sounding data are plotted on Fig. 3.

Comments: The soundings at all locations were essentially identical. Geologic conditions were either very uniform and homogeneous or for some other reason resistivity contrasts just did not exist. Pitfalls: adverse geology.

Electromagnetics (EM)

EM surveys are similar to DC resistivity surveys because they also measure the electrical properties of the subsurface. With this

Magnetics

A modern magnetometer, such as a proton procession device, is a powerful, cost-effective tool for delineating regions which contain buried ferromagnetic material, especially buried drums. However, the use of magnetic surveys often can fall short of the expected goal of accurately defining the region of burial. The following pitfalls frequently cause problems:

- Inadequate Survey Layout—The most effective survey lines should be oriented N-S, although in some cases this may not be practical. Readings should be taken at a minimum of every 10 ft along the profile. Initially, profile lines can be separated by about 30 ft, with additional lines added if anomalies are encountered.
- Cultural Interference—One cannot find buried drums when the surface is covered with scrap iron. Careful notes should be made by the field technician of the presence of any ferromagnetic material, such as "tin" cans, construction debris, buildings, fences, etc.
- Misinterpretation of Anomaly Patterns—Buried ferromagnetic material can produce a complex magnetic signature which frequently is subject to misinterpretation. In particular, with the orientation of the earth's magnetic field in North America, a buried drum will cause a magnetic high on the southern edge of the surface projection of a buried drum and a magnetic low to the north of it. Caution should be exercised when using complex deconvolution techniques to estimate the mass and depth of buried metal, although in some cases meaningful calculations can be made.

In addition to using a conventional magnetometer, a gradiometer (essentially two magnetometers in one, where the difference in response of two sensors at different elevations is recorded) is also commonly used. This system frequently is more efficient in determining whether or not buried ferromagnetic material is present, but it is subject to the same limitations as a conventional magnetometer and anomaly patterns are more difficult to interpret.

Case History Site 5

Site 5 was suspected of containing buried waste in drums, and a total field magnetic survey was conducted on a 10-ft grid to



Figure 4 Results of EM Survey at Site 4

locate this material. Data were contoured and interpreted to define three pit locations and a trench (Fig. 5).

Comments: Several mistakes were made in the interpretation. The linear anomaly trending E-W in the southern part of the site proved to be essentially surficial scrap metal which should have been noted in the field by the technician. The interpretor should have suspected the anomaly was surficial because of the absence of a pronounced magnetic low north of this anomaly. The sharp anomaly in the northwest corner proved to be an abandoned well casing that should have been noted by the field technician. The anomaly in the northeast corner did prove to be related to hazardous waste, but two pits were interpreted, whereas the anomaly pattern is indicative of only one source. Pitfalls: improper field procedures (inadequate note-keeping) and improper interpretation.

Ground Probing Radar (GPR)

The GPR technique has developed almost exclusively as a tool of engineering geophysics and as such is not generally familiar to most geophysicists with a background in the petroleum or mining industries. It is capable of generating in real-time, shallow earth profiles of dielectrical discontinuities related to subsurface conditions such as moisture content, lithology, bedding, voids, fractures, as well as man-made objects. When conditions are favorable, GPR profiles exhibit the greatest detail and resolution of any technique. However, conditions are seldom favorable and the pitfalls of measurement and interpretation are numerous, as outlined.

- Adverse Soil Conditions—Radar waves will not effectively penetrate damp, low-resistivity clay or other conductive material.
- Improper Antenna—The selection of the proper antenna is difficult to predict in advance, except in general terms. It is preferable to be prepared to try several frequencies between about 100 and 600 MHz before selecting the optimum frequency.



- Adverse Surface Conditions—In many cases, long grass is sufficiently conductive to present a problem of penetration. Rough ground can cause patterns to appear on the record when the antenna is bounced. These patterns can be confused with subsurface signals. Extreme care must be taken to assure that the movement of the antenna is smooth, and substantial surface grooming may be required.
- Cultural Interference—Small pieces of scrap metal on the surface can severely distort a GPR record, as can any buried metal object. An unshielded antenna can be affected by a nearby EM source, such as a power line. Rebar in an otherwise favorable concrete surface will severely distort a record.
- Improper Calibration—Unless a target at a known depth can be identified, depth is difficult to derive from a single antenna/ receiver. Where the antenna and receivers are separate, depth can be calculated following principles similar to the normal moveout correction employed by seismic reflection specialists.
- Improper Interpretation—Generally speaking, interpretation requires the intervention of an expert. The GPR method frequently records patterns that defy interpretation and much additional data frequently are required to make sense of the results.

No case histories of the GPR technique are provided. It is assumed that anyone who has familiarity with the method (unless that person's experience is with sand dunes, permafrost or ice) will be aware of case histories where the method did not work.

Seismic Refraction

The seismic refraction technique has long been a mainstay of the engineering geophysical profession, as it offers good potential for determining depth to bedrock, rock strength, depth to saturated soil or rock and rock and soil layering in general. Some of the limitations of the method are well known, especially that it will not identify any layer which has a lower seismic velocity than the layer above it. Fortunately for this method, ground conditions in natural terrain usually are favorable for conducting a good survey. Conditions at hazardous waste sites frequently are not as favorable, and special precautions must be taken. Typical problems are outlined below:

- Low-Velocity and/or Variable-Velocity Surficial Layer—Fill material commonly found at hazardous waste sites must be evaluated with extreme caution. Geophones must be closely spaced near the source to accurately measure the first layer velocity and identify any lateral velocity variations. Failure to do this can cause gross errors in determining the depth to deeper horizons. This implies that a survey at a hazardous waste site should utilize substantially more shot locations than a conventional survey.
- Data Quality—Industrial sites are frequently noisy, and it may be necessary to utilize sources of energy more powerful than normally would be used for a given spread length. The equipment should be capable of signal stacking to reduce noise. The field technician must be responsible for assuring that the first arrival waveforms are clearly and consistently defined.
- Interpretation—Simplified interpretations that can be based on hand calculations are not adequate for hazardous waste work, where the contacts between individual layers are frequently irregular. A number of acceptable processing/inversion programs which account for irregular layering are publicly available. It is important for the interpretor to have access to site geological data, preferably from borings, to obtain meaningful results.

The case history cites an example where good data were ob-

tained, but simplified interpretation led to substantial misinterpretation of the geological setting.

Case History Site 6

This site was the locality of extensive PCB spills over a number of years. Off-site migration in aquifers bounded by bedrock channels was considered possible, and a seismic refraction survey was conducted along the borders of the site. Hand calculations used to interpret the seismic refraction data did not indicate the presence of a bedrock channel (Fig. 6).

Comments: The hand calculations to derive depth to bedrock were complicated by the presence of three layers above the bedrock. Computerized inversion of the data with the Generalized Reciprocal Method defined the presence of a bedrock channel. The overall seismically-derived stratigraphy subsequently was confirmed by borings.

CONCLUSIONS

Much of the difficulty with the application of geophysical technology to problems of groundwater contamination and hazardous waste lies in the inexperience of the individuals conducting the surveys. Much of the work is conducted by hydrogeologists and civil engineers who do not have a strong background in geophysics. Conversely, the majority of geophysicists have their main expertise related to petroleum exploration and cannot be expected to be familiar with the specialized geophysical studies required for groundwater and hazardous waste studies. In some cases, a contracting or consulting firm may achieve competency with one specific method and tend to always employ that method, even if others would be better suited. The overall problem is well stated by Kendrick Taylor of the Desert Research Institute, Reno, Nevada, in a recent letter to Dr. Stanley Ward published in the February 1986 issue of *Geophysics: The Leading Edge:*

"Inaccurate information from both government and overzealous contractors and equipment manufacturers along with instant geowizards with no real background have on occasion raised expectations [of geophysics] to unobtainable levels that result in inevitable disappointments. At several recent conferences it was clear that the geophysicists could do the work but frequently had a difficult time relating it to hydrogeology and that hydrogeologists who were inquisitive enough to use geophysics, frequently did not use the methods in the most advantageous way. Hence, we see a situation with much confusion which in the long run discourages the use of geophysics."



Cross-Section of Site 6 Based on Seismic Refraction

In spite of the difficulties which have occurred in the application of geophysical technology to investigations at hazardous waste sites, many excellent surveys have been conducted. When properly applied by experienced personnel, geophysics is a powerful tool. With a minimum amount of site information, preferably with a site visit, the geophysicist usually can assess the probability of success of a given technique and define an effective program of study. Some locations are so adverse that geophysical techniques are not appropriate, but such locations can be defined in advance.

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Quality Assurance Testing of Monitoring Well Integrity

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ABSTRACT

The loss of monitoring well integrity may prevent the acquisition of reliable and representative results during groundwater quality investigations. Aside from faulty design and installation, loss of monitoring well integrity is the absence of casing or grout leaks either into the well or between aquifers. This definition is adapted from the concept of mechanical integrity in the U.S. EPA's Underground Injection Control Program. Loss of monitoring well integrity can result in inaccurate water level measurements, nonrepresentative water samples and cross-contamination of aquifers.

Potential methods of testing monitoring well integrity include well records inspection, cement bond logging, temperature logging, density logging, neutron logging, television logging, borehole televiewer, noise logging, tracer logging, caliper logging, pressure testing, pipe analysis survey and electromagnetic thickness survey. Most of these methods were developed for testing use in petroleum, mining or injection wells, which are generally deeper, wider and constructed and operated differently from conventional monitoring wells. Furthermore, these methods may lack the sensitivity to detect the types of leaks manifested by the microannuli of a failing monitoring well.

Most logging techniques are limited in applicability due to the small diameter and shallow depth of monitoring wells. Cement bond logs may produce the most reliable results to detect the integrity of a casing-cement-formation bond. However, casing leaks must be detected by other techniques such as television or caliper logs. Inspection of well records may be a successful means of qualitatively describing the viability of monitoring wells at installation, depending on the completeness of the well records. Comparisons of theoretical and actual grout usage may be used to imply good or poor grout emplacement. Where grout quality is suspect, compatibility tests with formation fluids should be performed to determine the ability of the grout to withstand chemical attack, especially where the aquifer is known to contain fluids that could aggressively attack the grout. Grout compatibility investigations should be part of monitoring system design.

INTRODUCTION

Once installed, the integrity of most monitoring wells is rarely questioned. As an integral part of groundwater quality investigations, monitoring wells are designed for the particular conditions to which the well and its grout, sand pack, seals, etc., will be subjected. Under ideal conditions, the well is installed by a competent driller under the supervision of a qualified geologist/ hydrogeologist/engineer who has the project perspective on the well's long-term purpose. Water quality investigations may extend over many years, and monitoring wells are expected to last with the study. Often, wells are needlessly replaced due to improper design or poor initial emplacement.

Inherent in this system is the potential for well failure. Well defects may occur as a result of improper design (e.g., incompatible materials or incorrect placement of seals), faulty installation (improper or sloppy methods), physical abuse from equipment or sitting idle between sampling episodes. With multistage groundwater studies and remediation projects, the wells' lifespans may extend over many years in contact with corrosive fluid. Defects may be severe, placing the validity of samples collected from the wells in question. Nonrepresentative samples may be obtained from wells which outwardly appear to be reliable.

Since even minute leakage into or out of the well could significantly affect the parts-per-billion analytical results obtained from analyses of groundwater from the well, such leakage must be detected. However, small leaks are difficult, if not impossible, to detect, especially in small-diameter monitoring wells.

This paper discusses the applicable methods of testing the integrity of monitoring wells and presents some ideas for identifying potential integrity problems during groundwater quality investigations. For complete descriptions of the available well logging methods, see Hearst and Nelson,' Nielsen and Aller,² Keys and MacCary³ and Kwader.⁴

TYPES OF WELL INTEGRITY PROBLEMS

Section 146.08 of the U.S. EPA's Underground Injection Control (UIC) Program (40 CFR Part 146) concerns the mechanical integrity of injection wells. According to these rules, an injection well has mechanical integrity if: (1) there is not significant leakage in the casing, tubing or packer, and (2) there is not significant fluid movement into an underground source of drinking water through vertical channels adjacent to the well.

The rules state that some combination of listed tests shall be used to evaluate the absence of significant leaks. The section also describes methods to demonstrate the absence of fluid movement, including: (1) well records demonstrating the presence of adequate cement to prevent such migration or (2) the results of a cement bond log, sonic log, temperature log, density log or neutron log. The following describes the applicability of these methods to monitoring wells. Additional methods not listed in the UIC regulations to test monitoring well casing and cement grout integrity are discussed in this paper. These well logging methods have not been widely incorporated into groundwater quality investigations, but may be helpful in assessing monitoring well integrity.

The UIC Program regulates wells used for subsurface injection of fluids such as industrial waste or oil field brines. It recognizes casing, tubing or packer leaks as the primary means of an injection well's loss of integrity. Monitoring wells are constructed differently from injection wells and have no open annulus, tubing or packer (Fig. 1). For monitoring wells, loss of integrity can be defined in terms of the four generalized types of problems shown in Table 1. Although any of the four types of problems described in Table 1 can affect the quality of samples obtained, this paper will address only potential means of detecting casing and grout leaks. Improperly placed gravel packs, seals and grouts may be significant factors in determining well integrity, but these problems are avoided by careful well design and installation.

MECHANICAL INTEGRITY TESTS

Well Records

The well records obtained during drilling usually contain information on types, sizes and lengths of casing and the types, quantities, weights of cement-based grout and methods of emplacement. These records probably do not indicate if the cement was successfully emplaced and an effective seal was obtained. However, an implication of good or poor grout emplacement may be possible by comparing estimates of theoretical grout requirements (based on annulus volume) with the actual volume of grout used. A severe discrepancy in volume used may indicate that the grout bridged the annulus during emplacement, leaving a section of annulus unsealed.

Cement Bond Logging

Cement bond logs can help evaluate the condition of grout behind the casing. These logs indicate the potential for fluid movement by monitoring the quality of the bond between the casing and the grout and between the grout and the formation. The logging method relies on the difference between the energy loss of a sound pulse traveling through casing that is free-standing in the hole and the energy loss of a pulse traveling through casing that is firmly bonded to a hard material of a low sonic velocity, such as cement grout.

The cement bond log, which is a type of sonic log, indicates whether the cement is bonded to the casing and to the formation. However, it should be pointed out that this only indicates the presence or absence of an adequate bond. In rock where there are known vertical and horizontal fractures, these also would be detected as poor bonding. The cement bond does not detect fluid migration behind the casing; it indicates whether such a potential exists.

Temperature Logging

Three types of temperature logs currently are available: conventional, differential and radial differential. The temperature of the earth increases with respect to depth except for approximately the first 100 ft, which are influenced by partial fluid saturation and seasonal variations in temperature. Below this depth, the temperature gradually increases at a rate of approximately 1 °F per 100 ft. Conventional and differential temperature logs record minute changes in temperature as a function of depth. The differential temperature log more sensitively measures the geothermal gradient, detecting slight changes in well temperature. The radial differential temperature log measures the variations in temperature in the plane of the casing radius at two points. It can locate channeling behind the casing by detecting minute temperature anomalies.

Temperature logging methods are most advantageous in wells deeper than 100 ft. Their application to monitoring wells should be considered where there is a temperature differential between the aquifers penetrated by the well.

Density Logging

The density or gamma-gamma log is primarily a tool for meas-

uring porosity by measuring the electron density of a material. It measures the intensity of backscattered gamma radiation emitted by the density log probe. The results of the log indicate the presence of grout within 6 in. of the casing center, but may not provide detailed information on the adequacy of the grout. Density logging should be considered when gaps in the grout are suspected.

Neutron Logging

The neutron log operates by emitting and receiving neutrons. Cement grout contains more interstitial water than surrounding rock formations and less than groundwater. The neutron log thus can distinguish between grout, rock and groundwater by different degrees of neutron attenuation. The method may give some indication about the presence or absence of grout. However, hydrocarbons found in many groundwater studies may give anomalous results in neutron logging.

Television (Visual) Logging

Television borehole logging has been used to visually inspect casings by providing a continuous videographic log of the inside well casing surface. This simple technique has some clear disadvantages. The minimum well diameter is 3 in. If the casing is corroded or dirty, the camera will not detect holes or cracks in the casing. Small cracks or holes are difficult to detect. Visual logging may detect larger pits in the casing which are not channels for fluid movement. Therefore, this test is not sensitive enough to distinguish channels for small leaks but is recommended where large holes or structural failures have occurred.

Borehole Televiewer

With high-frequency acoustic energy, the borehole televiewer scans and provides an image of the inside casing surface. Casing defects are visible on the resulting log to an experienced log analyst. The televiewer is available in smaller sizes than the visual television logging device and can log through most homogeneous liquids. Disadvantages include limited experience in cased wells and limited commercial availability of the equipment.

Noise (Acoustic Emissions) Logging

Fluid flowing through restrictions as leaks in the well casing or channels behind the casing generate distinctive sound frequencies. A sophisticated microphone traveling up the well can detect and pinpoint the sound, provided the leak and the pressure changes are of adequate magnitude. Noise logging is ideal for injection wells which are under pressure, as fluid leaking from the well would undergo a significant pressure drop and could spurt, emitting a specific sound. Noise logging may not be helpful in detecting leaks in monitoring wells with insufficient pressure differentials between the aquifers penetrated by the wells. The technique, however, may be appropriate given adequate research and development into the instrumentation sensitivities, reliability, reproducibility and data interpretation.

Radioactive Tracer Logging

Radioactive tracers have been used by mixing the tracers with well fluid and with cement before group emplacement. Tracers in well fluid may be pressurized in the casing with a packer at the bottom. If a casing leak is present, the tracer may enter the annulus or formation and be detected after flushing the casing. Due to the sensitive nature of monitoring well uses for groundwater assessments, radioactive tracers are not highly recommended.

Caliper Logging

Mechanical calipers contact and measure the inside casing surface with a range of sensitivity (2 to 64 feelers), producing a profile of the inside diameter with depth. Caliper logging is a simple method of inspecting casing by detecting and signaling irregularities on the inner surface of the casing. One disadvantage is that holes smaller than approximately 0.5 in. in diameter and vertical cracks may go undetected by the calipers as they are raised along the well. Caliper logging may detect casing pits which are not in danger of becoming channels for fluid movement and may help evaluate the quality of grout seals at the bottom of casings in wells with open hole completion. Caliper logging is useful in detecting variations in casing diameter due to chemical destruction of the casing.

Pressure Testing

Pressure testing can locate casing leaks in a monitoring well by using two packers in staged pressure tests. An isolated casing interval may be pressurized using a fluid such as water while monitoring the pressure drop. Pressure tests can detect sizable casing leaks, but do not detect grout leaks. An incomplete packer seal may be confused with a casing leak. However, results of pressure tests may contribute to the assessment of monitoring well integrity.

Pipe Analysis Survey

The pipe analysis survey was developed to detect downhole corrosion damage such as holes, gouges or cracks by measuring fluctuations in an induced magnetic field. Using high-frequency eddy current and magnetic flux leakage tests, defects on the inner surface and the outer surface of the casing wall can be distinguished by a skilled log analyst. The survey can detect damage as small as 0.125 in. on the inner casing wall and 0.375 in. on the outer casing wall. Although the pipe analysis survey is one of the best available methods for detecting casing defects, it does not provide information about fluid movement and can be run only in steel-cased wells.

Electromagnetic Thickness Survey

The electromagnetic thickness survey measures the phase shift of an induced magnetic field and detects casing deterioration, including large-scale corrosion, casing splits and mechanical wear. However, the log is dependent on the magnetic and electrical properties of the casing being surveyed. It is difficult to discern whether a log anomaly is due to loss of metal from the casing or a change in casing properties. The logging method is limited to metal casing wells with outside diameters between 4.5 and 9.625 in. The resolution also is limited to pits or holes at least 1 in. in diameter.

DISCUSSION

None of the test methods described above can verify conclusively the absence of casing or grout leaks in monitoring wells, although some methods provide a higher degree of confidence than others. Monitoring well integrity testing is most conclusive with the detection of leaks or poor grout seals. Tests interpreted to indicate the absence of leaks may only reflect an improper or insensitive test, regardless of the well's integrity.

The best way to increase the level of confidence of a testing program is to incorporate several test methods into the program. For logging techniques, this generally is quite feasible, as most well logging service companies can provide several of the recommended methods. Also, the most logistically cost-effective approach usually is to conduct a testing program in stages, initially inspecting well records, followed by a limited logging program to test the applicability of selected methods to individual wells. The limited logging may be followed by more comprehensive logging, testing additional wells at the site. Following analysis of the logs, pressure tests may be used selectively on individual wells for which the logs are inconclusive or indicate a high probability of leakage. The selection of a particular test method may depend on the type and scale of the integrity problem experienced by the well in question; however, any symptoms exhibited by the well may be subtle and may not provide sufficient insight into the nature of the problem. For example, if large-scale casing leaks are suspected, caliper logs would be appropriate, possibly supplemented by borehole television. For suspected grout problems, cement bond logging is the most widely recommended method and may be accompanied by density logs.

Site-specific factors need to be considered in the design of any testing program. Well construction details will dictate the applicability of techniques such as pressure testing, pipe analysis survey and borehole television. Well depths and hydraulic gradients between aquifers are important in determining the viability of temperature logging and noise logging, respectively.

The costs of performing a logging program generally can be separated into three main elements: (1) rental and mobilization costs for the logging equipment (usually truck-mounted), (2) personnel costs to operate the equipment on the site and (3) interpretation costs by an experienced well log analyst. For a given program, these three elements represent approximately equal portions of the total cost.

All three of the cost elements are scale-dependent; the more wells tested or the deeper the wells, the lower the per-foot or per-well costs. Increasing the number of well logs will increase the project costs, but not always in direct proportion to the number of logs. Interpretation time is an important factor in total costs; however, the level of effort required is dependent on the complexity of the logs, the number of logs, the ability to cross-correlate the logs and the subtlety of the integrity problems.

GROUT COMPATIBILITY

The question of monitoring well integrity may be partly answered by assessing the grout's compatibility with its environment. The assessment may be conducted both by library and by laboratory, both before and after well emplacement.

Studies of grout durability in the presence of hazardous wastes and leachates have been conducted for construction, slurry wall and waste isolation projects; the information has been collated by publications such as Spooner et al.⁵ Although the information is far from complete, it may contribute to choosing the most durable grout for a given environment. Spooner, et. al., have produced matrices of known and predicted effects of different chemical groups on the set time and durability of various grout types. From this and additional information, an appropriate grout may be chosen for specific areas of a contaminated site.

Little information is available about the combined effects of different chemical groups on a grout. One can perform laboratory tests in combination with library search information to establish the compatibility of a specific hazardous waste with the grout. Fixed-wall and triaxial permeameters can be used to measure the effects of chemicals on permeability. Visual observation, although subjective, is one of the easiest methods for recording set time changes due to chemical interactions.

CONCLUSIONS

Logistically, the currently available tests to detect leaks in the casing or fluid movement are not always applicable to monitoring wells. These tests were developed for oil, mining or disposal industry wells which are deeper, wider and under pressure. Further, injection wells which are pressurized regularly are more likely to crack or wear the casing and cement grout. No single well logging method stands out as the solution to monitoring well integrity problems. The scale of sensitivity needed for leak testing in

Table 1 Types of Monitoring Well Integrity Problems

TYPE OF PROBLEM	POSSIBLE CAUSE(S)	POTENTIAL EPPECT
Casing Leake	Mechanical casing damaged before, during, or after installation; material chemical incompatibility	insccurste water levels, gross-contemination of mmpies and aquifer(s)
Grout Leaks	Poor grout bonding; grout/aquifer incompatibility, grout eracking from mechanical disruption; improper grout mixtures	inaccurste water levels, cross-contensination of samples and equifer(s)
Improper Grave) Pack/Seals	Poor well design; sloppy seal Installation	Excessive siltation; grout contamination of groundwater samples
Improper Seal/Grout	Poor design, faulty installation	Cross-contamination of

monitoring wells exceeds the needs of most larger wells. A small crack or hole spreading a few parts per million of contaminants to another zone generally is not detectable by the methods designed for injection wells. A combination of present logging methods supplemented by pressure testing may be used to interpret monitoring well integrity. Casing integrity and grout integrity may be established best by noise or cement bond logging methods. All test methods require interpretation by qualified analysts to maintain reasonable confidence levels.

Assessing the durability and compatibility of monitoring well grout may also provide clues to the problem of well integrity. Laboratory tests of grout durability may support confidence in the present monitoring well integrity. During planning stages, a suitable grout can be chosen in consideration of the groundwater chemistry of a hazardous waste site. The choice does not necessitate expensive laboratory time; it can be made from literature surveys.



Figure 1 Typical Injection and Monitoring Well Designs

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Leachate Characterization and Synthetic Leachate Formulation for Liner Testing

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ABSTRACT

A U.S. EPA-sponsored study was conducted to characterize leachates from hazardous waste land disposal sites and to assess the feasibility of formulating a multi-compound synthetic leachate for liner testing. Leachate samples from 13 hazardous waste disposal sites were analyzed for priority pollutant metals and organic compounds, other organic compounds, total cyanide, total organic carbon, chemical oxygen demand and various other general parameters.

The analytical data were evaluated to characterize the occurrence frequency and concentrations of detected constituents in the leachates. Conclusions were made regarding the feasibility of formulating a synthetic leachate based on the study data. Recommendations were made for approaches to representing constituents in a leachate formulation and for followup analytical programs which would more comprehensively characterize leachates and enlarge the organic constituent data base.

INTRODUCTION

The Hazardous Waste Engineering Research Laboratory-Cincinnati (HWERL) of the U.S. EPA Land Pollution Control Division is developing a data base containing information about a variety of hazardous wastes and associated leachate compositions. The data base is required to assess the feasibility of formulating multi-compound synthetic hazardous waste leachates for testing containment liners under consideration for use in landfills and other hazardous waste storage, treatment and disposal facilities. Liner and chemical compatibility experiments generally have involved testing only a single chemical compound or waste. Therefore, any synergistic effects on liners that might be caused by multi-compound hazardous waste leachates generated from complex waste mixtures are relatively unknown.

The U.S. EPA sponsored a study in 1985 to gather data on the composition of leachates generated by operating hazardous waste disposal sites. An assessment was made regarding the feasibility of formulating a synthetic leachate based on the study data. The data can also be used by other researchers to predict the chemical compositions of leachates generated by various hazardous wastes and as a general reference on leachate composition.

This paper presents the study approach, selected results and recommendations for both synthetic leachate formulation and followup analytical programs. Another U.S. EPA-sponsored study which incorporates some of these recommendations was initiated in June of 1986. The results of this new study were not available at the writing of this paper.

DESCRIPTION OF SITES SELECTED FOR LEACHATE COLLECTION

The leachate samples characterized during this study were collected from 13 professionally operated hazardous waste landfills. These sites were selected from a master list of 43 operating landfills which accepted either only hazardous wastes or a combination of municipal and hazardous wastes. Besides willingness to participate, criteria for site inclusion in the study involved consideration of the following:

 Existence of a leachate collection system and system accessibility for sample collection

 Table 1

 Overview of Thirteen Sites Selected for Leachate Sampling and Analysis

Site Number	Site Age (Years)*	Waste Type Input*	Geographic Location in the U.S.	Net Precipitation Range (Inches)
1	3	Alkaline inorganics; liquids and solids; 40% drummed/60% bulk	Southern	-10 to +5
2	3	Variety, specifics not svsilable; all bulk solids	Southern	+10 to +15
3	5	Wide veriety; inorganic and organic; solide only, drummed and bulk	Southern	+5 to +10
4	٠	Wide variety; organic concentrations < 5%; solids only; 25% drummed/75% bulk	Central	-10 to +5
5	5	Wide variety; inorganic and organic; mostly containerized solids and liquids	Western	< -10
6	3.5	Variety; mostly petrochemical and electropisting westes; solids only; drummed and bulk	Western	< -10
7	6	95% wastewater treatment sludge; some drummed liquids	Northeastern	+5 to +10
8	7	65% wastewater biological treatment sludge, 18% phthalate/benzyl chloride waates; 15% lime grit; bulk solids only	Northeastern	+5 to +10
9	13	Variety; inorganic and organic; drummed non-halogenated solvents and oily residues; bulk pigments	Northeastern	+10 to +15
10	2	Variety; including incinerator and refinery wastes, asbestos, fly ssh; drummed and bulk, no free liquids	Centrel	—10 to +5
n	10	Wide variety; organic and inorganic, drummed and bulk	Northeestern	+5 to +10
12	5	70% PCB-containing materiels, 29% westewater treatment skudge, 1% cyanides and corrosives; 20% drummed/60% bulk	Central	+5 to +10
13	5	Wide variety; inorganic and organic; solids only; drummed and bulk	Southern	+10 to +15

*This information is only for the sampled portion of a site.

- Period of site operation, i.e., for 5 yr or at least long enough to generate leachate at a sufficient rate for sample collection and at a quality representative of disposal wastes
- Available and reliable information regarding the types of wastes disposed at the site
- Contribution to an overall site profile which illustrated waste type, geographic and climatic diversity

One study objective was the generation of a data base representing a wide spectrum of existing leachate characteristics. The sites finally selected for inclusion were located in various geographic sections of the United States, thereby representing to some degree varying climatic conditions. The sites also varied in the relative quantities, types and physical forms of the wastes accepted for disposal (e.g., containerized liquids versus bulk solids); the landfill disposal operating practices (e.g., cover material and frequency of cover application); and the period of site operation. All of these factors plus others can interrelate and impact the generation rates and chemical characteristics of the respective leachates. Table 1 provides an overview of the 13 sites finally selected for leachate sampling and analysis.

LEACHATE SAMPLE COLLECTION AND ANALYTICAL PARAMETERS

Collection of leachate samples from each of the 13 sites occurred between June 9 and 21 of 1985. Sample collection was conducted as close as possible to the generation source to maximize sample representativeness of actual leachate quality. However, points of collection varied depending on system design and leachate accessibility. Sample collection points included leachate collection system sumps, bleeder valves, pipe discharges into drainage channels, recently filled storage tanks and, in one case, a storage lagoon.

Field tests (i.e., pH, temperature, redox potential and specific conductance) were performed on-site. Laboratory analyses included tests for volatile organics; semi-volatile organics, including acid and base/neutral extractables; heavy metals; total cy-anide; total organic carbon (TOC); and chemical oxygen demand (COD).

Laboratory analyses involved standard U.S. EPA procedures and protocols. Samples for the organic analyses had to be diluted five or ten times to reduce their high chemical concentrations to testable levels. A 24-hr continuous liquid/liquid solvent extraction system was used during the analyses of semi-volatile organics rather than the separation funnel technique in order to avoid emulsion formation.

OVERVIEW OF THE ANALYTICAL RESULTS

The data generated from the analyses of the leachate samples during this study are too extensive to present completely in this paper on a sample-specific basis. However, general information regarding the occurrence of the components and the ranges of certain parameter levels will be presented. A report which presents the details and complete results of this study was submitted to the U.S. EPA in September 1985 and will be made available to the public.¹

Field Tests and COD Data Results

Sample temperature, pH, redox potential and specific conductance were measured at the time of sample collection. Data for these parameters, however, were not considered reliable for every site because of suspected field instrument malfunction.

Leachate temperature was measured at 5 of the 13 sites and ranged from 20 to $32 \,^{\circ}$ C, with a mean of $27 \,^{\circ}$ C and a standard deviation of 6.2 $^{\circ}$ C. The parameter of pH was measured at 5 sites and ranged from 7.1 to 9.3, with a mean of 8.2 and a standard deviation of 0.857. Redox potential was measured at only 3 sites and was recorded as -0.343, -0.241 and -0.093.

Specific conductance was measured at 9 of the 13 sites. A specific conductance greater than 20,000 micromhos/cm was measured in samples from Sites 4, 6, 8 and 10. The specific conductance of samples from the other 5 sites ranged from 4,250 to 12,000 micromhos/cm.

Laboratory analysis for COD was performed on samples from all of the sites. The results ranged from 1,950 to 23,300 mg/l, with a mean of 10,217 ppm and a standard deviation of 6,475 mg/l. Samples from Sites 3, 4, 5, 6, 7 and 9 had COD measurements of less than 10,000 mg/l.

Inorganic Data Results

Each of the 13 samples was analyzed for 13 metal priority pollutants including silver, arsenic, beryllium, chromium, cadmium, copper, mercury, nickel, lead, antimony, selenium, thallium and zinc. Most of the metals were detected in every sample except mercury, antimony, thallium and beryllium. Generally, the metals were detected only in the low or fractional mg/l. Beryllium was the least commonly detected metal and was detected only in samples from six sites.

Arsenic and selenium were the most common of the metals detected at least once at levels greater than 1 mg/l. They were detected in samples from 7 sites each, followed by nickel and zinc in 5 samples each and copper in 4 samples. The samples collected from Sites 1, 3, 6 and 12 contained 5 or more metals at concentrations greater than 1 mg/l, including selenium and zinc in all cases.

Total cyanide was detected in samples from 9 sites. Cyanide levels ranged from 0.01 to 55 mg/l. Five of the leachate samples contained total cyanide at levels less than 1 mg/l. The highest levels of total cyanide were 27.6, 40 and 55 mg/l and were detected in samples from Sites 11, 1 and 3, respectively.

Total Organic Carbon Results

Total organic carbon (TOC) was determined to gauge how successfully analysis had identified the organic constituents. The constituents have been comprehensively identified if analytical TOC equals the calculated TOC of the whole sample based on measured combined quantities of individual organic compounds.

The analytical TOC values ranged from 195 to 11,750 mg/l. The percentage of the analytical TOC accounted for was less than 10% for 11 of the 13 leachate samples and less than 5% for 6 of the 13 samples. A substantially larger percentage of the analytical TOC was accounted for by the calculated TOC in samples from Sites 5 and 9, 40.4 and 59.5%, respectively. These samples also had the lowest analytical TOC values at 195 mg/l (Site 5) and 309 mg/l (Site 9).

The low percentage of analytical TOC accounted for reflects substantial concentrations of non-volatile low or high molecular weight organics or other constituents which do not extract or successfully chromatograph using routine and standard analytical methods. Three other possible explanations for the low accountability of TOC include:

- The incomplete extraction of water soluble semi-volatiles may have occurred during sample preparation.
- A combination of sample concentration (very high in organics) and sample complexity (a large number of diverse compounds) may have caused misidentification of compounds. This is unlikely because the mass spectrometric results were computer matched. However, GC peak overlap was observed and, even with the identification of peak components by mass spectrometry, concentration errors may have occurred.
- The GC/MS methodology was highly sensitive, and most of the leachate samples contained a large organic component. There-

fore, the samples required large dilutions to keep the readings on scale. These dilutions increased the minimum detection limits for the compounds, which ranged from as little as $25 \ \mu g/l$ to as much as 10,000 $\mu g/l$. As a result, many trace constituents which may have been detectable in an undiluted sample were rendered undetectable by the large dilutions.

Organic Data Results

The leachate samples were analyzed for 35 volatile and 68 semi-volatile organic priority pollutants. In addition to the detected priority pollutants, 84 non-priority pollutant compounds and families of compounds were identified by matching GC/MS spectra with a library compiled from National Institute of Health and U.S. EPA libraries.

All of the detected organic compounds were grouped into the six general classes of organic compounds which are frequently used to discuss the compatibility of chemicals with various containment liners. These classes include organic acids, oxygenated/heteroatomic hydrocarbons, halogenated hydrocarbons, organic bases, aromatic hydrocarbons and aliphatic hydrocarbons.

The overall characterized TOC on average equalled approximately 4% of the total sample analytical TOC. Assignment of this characterized amount to the six classes mentioned above (based on mole fraction) is as follows (in decreasing order): organic acids, 39%; oxygenated/heteroatomic hydrocarbons, 35.8%; halogenated hydrocarbons, 11%; organic bases, 7.2%; aromatic hydrocarbons, 6%; and aliphatic hydrocarbons, 0.9%. In general, the classes containing compounds with relatively high aqueous solubilities accounted for higher mean mole fraction percentages than did the classes containing compounds with lower aqueous solubilities.

A summary of the leachate organic compound occurrence data is presented in Table 2. The following observations were made based on all of the data:

• Organic acids, as a class, were approximately 55% (by mole fraction) phenol and substituted phenols and 45% carboxylic acids, including benzoic acid and alkanoic acids with 4 or more carbon atoms. The compounds detected in leachate samples from the greatest number of the sites were phenol (13 sites), 4-methylphenol(12 sites), 2-methylphenol (10 sites), 2-4-dimethylphenol (9 sites) and benzoic acid (8 sites).

 Table 2

 Summary of Leachate Organic Chemical Occurrence Data

Chemical Classification	Percent Occurrence (Total Mean Mole Fraction)	Representative Chemicsks) and Occurrence (Total Meen Mole Fraction)
Organic Acids	39.0%	Phenol (11.8%)
		Substituted Phenois (17 compounds at 9.5%)
		Benzoic Acid (5.3%) and Substituted Benzoic Acids (4 compounds at 0.1%)
		Alkanoic Acids (13 compounds at 12.3%)
Dxygenated/Heteroatomic	35.8%	Acetone (16.5%)
Hydrocarbons		Common Katone Solvanta, e.g., 2-Hatanone, 2-Butanone, and 4-Methyl-2-pentanone (9.2%)
		Alcohole of all types (16 compounds at 8.1%)
alogenated Hydrocarbons	11.0%	Methylene Chloride (6.8%)
		Chlorobenzenes (4 compounds at 1.4%)
		Multichlorinated Alkanes/Alkanes (10 compounds at 2.8%)
Ingenic Bases	7.2%	Anline (2.9%) and Substituted Anlines (6 compounds at 1.4%)
Vomatic Hydrocarbona	6.0%	Toluenes (4.2%)
		Benzene and Alkyl-substituted Benzenes (except Toluenes) (1.4%)
liphatic Hydrocarbons	0.9%	This group did not have any good representatives in terms of level of occurrence.

• The oxygenated/heteroatomic hydrocarbons, as a class, were approximately 46% acetone, 26% common ketone solvents and 23% alcohols. The compounds detected in samples from the greatest number of sites were acetone (13 sites), 2-hexanone (13 sites), 2-butanone (12 sites), 4-methyl-2-pentanone (11 sites) and di-n-butylphthalate (9 sites). Methanol or ethanol was not detected in leachate from any site. The various ethers, esters and aldehydes were infrequently detected in low concentrations. These three groups were not well represented by any particular compound.

- Methylene chloride accounted for approximately 61% of the halogenated hydrocarbon occurrences. Dichlorinated benzenes and chlorobenzene accounted for about 13%, but these compounds generally were not widely distributed and only occurred at less than half of the sites. The compounds detected in samples from the greatest number of sites were methylene chloride (13 sites), trichloroethylene (11 sites), chloroform (10 sites), tetrachloroethylene (7 sites) and chlorobenzene (6 sites).
- Organic bases were present in leachates from nine sites. A single organic base did not occur at half or more of the sites. Although aniline ranks first by a large margin in the mean mole fraction percentage represented, it was detected in samples from only 3 of the 13 sites sampled.
- Toluene, benzene and other alkyl-substituted aromatics accounted for approximately 92% of the aromatic hydrocarbon class. The aromatic hydrocarbons detected in samples from the greatest number of sites were toluene (13 sites), benzene (12 sites), total xylenes (11 sites), ethylbenzene (10 sites) and naphthalene (4 sites). Toluene ranks first by a large margin in the mean mole fraction percentage represented.
- Aliphatic hydrocarbons occurred infrequently and were only detected in samples from 3 of the 13 sites.

Pesticide Data Results

A GC/ECD analysis for PCBs and chlorinated pesticides was carried out on the sample from Site 12, at which 70% of the wastes were PCB-contaminated materials. Seven different PCBs and pesticides were detected in the sample. In order of concentration from highest to lowest (in μ g/l) the compounds were: endosulfan sulfate (14.8), endrin ketone (11.4), heptachlor epoxide (8.6), dieldrin (4.5), 4,4'-DDD (2.2), endrin (1.9) and alpha-BHC (1.7). The combined contribution of these substances was negligible at less than 0.01 mole fraction percentage. In addition, the above compounds accounted for only a very small part of sample analytical TOC.

RECOMMENDATIONS REGARDING SYNTHETIC LEACHATE FORMULATION

The results of this study do not collectively characterize any particular leachate which was generated by any particular waste or land disposal unit. Instead, as intended, the data represent an integration of leachate qualities exhibited by a variety of professionally operated hazardous waste landfills. A synthetic leachate for actual liner testing could not be formulated based on a 4% characterized organic fraction. Organic compounds that exist within the 96% of uncharacterized TOC can impact the effectiveness of liners and thus deserve to be represented in a synthetic leachate. Nevertheless, useful information about the composition of actual leachates has been revealed, particularly with respect to the relative distribution and representation of the six organic classes. Additionally, recommendations can be made in regards to approaches for future studies which would generate a more complete data base on organic constituents.

The study did characterize completely the concentrations of priority pollutant metals in the various leachates, finding that the most common metals were arsenic, selenium, nickel and zinc. Additionally, other parameters were quantified for many of the samples and demonstrated a range of values. Nevertheless, liner compatibility tests have shown that heavy metals in saturated solutions generally are compatible with flexible membrane liners and that inorganic constituents mostly affect only soil and clay materials.^{2, 3} Additionally, reference materials regarding the importance of cyanide, redox potential and COD with respect to leachate and liner compatibility are scarce. Most, if not all, liner materials also are affected by very high or very low pH values. For all of these reasons, only guidelines for the selection of organics and pH levels are recommended.

The pH values which were reported during this study ranged from neutral to mildly alkaline. Based on these results, a value range of 7 ± 2 is proposed as a reasonable pH for a synthetic leachate.

A synthetic leachate also should be approximately 99% water and 1% organics by weight. This estimate is based on an analytical average TOC of about 0.3 g/100 ml of sample, or about 0.3% carbon. This amount of carbon would produce a weight of 1 g (or less) of organic compounds/100 ml.

Several approaches can be taken toward the formulation of a synthetic leachate once a sufficiently complete data base is generated on the organic constituents of actual hazardous waste leachates. Tables 3 and 4 present examples for three such approaches by using the results of this study. These formulas should be viewed only as prototypes, intended only to illustrate possible approaches to leachate formulation, and not as strict examples of what constituents and concentrations should be in such formulations.

 Table 3

 Example of a Generic Synthetic Leachate Formulation

Example(s)	Mole Fraction Percentage
Phenol, Cresols	21
Benzoic, Hexanoic	18
Acetone, 2-Butanone, 4-Methyl-2-pentanone	26
Benzyl, Hexanol	10
Methylene Chloride, Chlorobenzene	11
Aniline	7
Toluene, Benzene	6
Heptadecane	1
	Example(s) Phenol, Cresols Benzoic, Hexanoic Acetone, 2-Butanone, 4-Methyl-2-pentanone Benzyl, Hexanol Methylene Chloride, Chlorobenzene Aniline Toluene, Benzene Heptadecene

Table 3 presents a generic synthetic leachate formula; it simply proposes at what proportions the organic classes should be represented, as supported overall by a data base. Each organic class is represented by only a few specific compounds (such as those given as examples in the table) at the respectively appropriate mole fraction percentage. The constituents and class proportions should be supported by representations in the data base. For example, based on the results of this study and as presented in the table, the organic acid group consists of representative phenols and carboxylic acids in approximately equal proportions with respect to mole fraction; the oxygenated/heteroatomic group consists of representative ketones and alcohols, in a ratio of about two to one, respectively.

Table 4 presents two synthetic leachate formulas which are more chemically complex and specific than the generic formula of Table 3. Each organic class still is represented in the formulas by that proportionate amount supported by the overall data base, but many more chemicals are selected to represent each class.

 Table 4

 Examples of Two Specific Synthetic Leachate Formulations

	Compound Contribution as a Mole Fraction (m.f.) Percentage			
Compound	Synthetic Leechste A Chemicals Occurring et ≥ 5 Sites	Synthetic Leschate 8 Chemicals Occurring at Average Concentrations ≥ 1.0 m.f. (x100)		
ORGANIC ACIDS				
Phenot	12%	12%		
4-Methylphenoi	6%	6%		
2-Methylphenol	3%	5%		
2,4-Dimethylphenol	2%	-		
2-Methylpropenoic Acid	-	15		
Benzoic Acid	6%	8%		
Phenylecetic Acid		-		
Butanoic Acid		4%		
Pentenoic Acid	2.1	76		
Hexenoic Acid		2%		
2-Ethylhexanoic Acid		-		
Subtotal	3676	38%		
OXYGENATED/HETEROATOMIC				
Acetone	17%	16%		
2-Butanone	5%	7%		
2-Hexanone	3%	4%		
4-Methyl-2-pentanone	2%	_		
Di-n-butviohthelate	1%	-		
Benzyl Alcohol	8%	8%		
Subtotal	36%	39%		
HALDGENATED HYDROCARBONS				
Methylene Chloride	5%	9%		
Chlorobenzene	1%	-		
1,2-Dichlorobenzene	-	2%		
Chloroform	1%			
Tetrachiorethylene	1%			
Trichlorethylene	196			
1,1,1-Trichloroethane	196	-		
trans-1,2-Dichloroethylene	1%	-		
Subtotal	11%	11%		
ORGANIC BASES				
Aniline	-	3%		
N, N-Dimethylacetamide	-	4%		
4-Methylbenzenesulfonamide	7%	-		
Subtotal	7%	7%		
AROMATIC HYDROCARBONS				
Toluene	3%	6%		
Ethylbenzene	1%	-		
Xylene(s)	196	-		
Benzene	1%	-		
Subtotal	6%	6%		

The specific formulas differ based on the criteria used to select the chemicals and the respective proportions. The criterion for chemical inclusion in Synthetic Leachate A is the frequency of chemical occurrence in samples, i.e., a chemical is included if it was detected in leachates from five or more sites. The criterion for chemical inclusion in Synthetic Leachate B is the detected concentration of a chemical, i.e., a chemical is included if it was detected at average concentrations greater than 1.0 mole fraction percentage. Chemical class and chemical proportionate contributions to the synthetic leachate are shown in the table by a mole fraction percentage and again should be dependent on the supporting data.

The leachate samples collected during this study were approximately 1% organic by weight. Organic concentrations can vary with time and location within a site as the wastes age and change in composition. Additionally, a punctured and corroded container can result in a localized and highly concentrated organic contact with a liner. Compatibility tests which use a synthetic leachate containing an organic portion much greater than 1% may be performed to represent such a situation.

RECOMMENDATIONS REGARDING ANALYTICAL PROGRAMS FOR SIMILAR STUDIES

Subsequent leachate characterization studies ideally should include analytical programs which employ state-of-the-art techniques designed to more fully characterize the organic materials. Studies initially should be limited in scope to characterizing leachates from one or two facilities and thereby first evaluate the adequacy of any proposed analytical program. The analyses of samples from sites which accept a wide variety of waste types, such as commercial facilities, would probably best gauge a program's ability to identify a variety of compounds.

Based on observations regarding the limitations of this study's analytical scheme, the following approaches are recommended with regard to subsequent studies:

- Total recoverable oil and grease analyses could be performed on the samples to improve the mass balance results (i.e., the agreement between analytical and calculated TOC). This information could be very helpful in characterizing at least part of the organic fraction.
- In addition to carrying out oil and grease extractions, other separation procedures could be attempted. Silica gel column chromatographic separation into polar, aromatic and aliphatic fractions before GC/MS analysis would permit better separations by GC and more reliable identification by MS. Also, a TOC or oil and grease analysis on an aliquot of each column chromatographic fraction would allow an assessment of material balance during analysis.
- Alternatively, general chemical classes could be analyzed, rather than specific organic compounds. For instance, total inorganic halogen, total phenols and oil and grease could be included as key parameters.
- A determination of the amount of water could be performed on the sample. This procedure would give direct information about the extent of the aqueous portion of the leachate.
- A determination of whether the leachate sample is homogenous or has a separable organic fraction that either floats or sinks could be made. This factor would determine whether or not a mainly aqueous phase or a mainly organic phase is in contact with the liner. An analytical scheme could be developed, if preferred, only for that phase in contact with the liner.

At the writing of this paper, another U.S. EPA-sponsored study is underway which incorporates some of the above recommendations. This effort's analytical scheme hopefully will characterize more fully the organic content of leachate. The first phase of this new study involves the application of the analytical program to one sample to gauge its effectiveness. If the initial results are not satisfactory, changes may be made to this program's scope before its application to two additional samples.

CONCLUSIONS

The routine analyses of 13 hazardous waste leachate samples resulted in the complete characterization of priority pollutant metals and the incomplete characterization of organic constituents. However, the results did provide valuable information regarding the relative distribution and representation of six organic classes.

Nevertheless, a synthetic leachate could not be formulated based on these results alone. However, several approaches can be suggested regarding the selection and relative concentrations of constituents in a synthetic leachate formula for consideration once a sufficient data base is available. Such approaches might include the development of a generic formula in which each organic class is represented by a few of the compolunds most commonly encountered in actual leachates. Other approaches might include developing formulas in which many more chemicals are represented. The criteria for chemical inclusion in these more specific formulas might be based on whether the chemicals frequently occurred in a number of actual samples or whether the chemicals were detected above a certain proportionate concentration.

Future studies should employ an analytical program which is specifically designed to more comprehensively characterize the organic components of actual leachates. This approach is particularly relevant with respect to formulating synthetic leachates for liner compatibility studies because organics have been particularly aggressive agents toward such liners. A study which incorporates such an analytical program is currently underway and is being sponsored by the HWERL of the U.S. EPA.

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Environmental Behavior of Polynuclear Aromatic Hydrocarbons at Hazardous Waste Sites

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ABSTRACT

Complexities in the analysis and environmental fate of polynuclear aromatic hydrocarbons associated with inactive wood treating and gasification sites have led to problems in interpretation of results. This paper presents a preliminary investigation of a methodology developed in response to these problems. A chemometric profiling technique involving pattern recognition is proposed and investigated in relationship to source apportionment and environmental fate and transport. Examples of PAH profiles from several inactive waste sites are examined and interpreted regarding site management.

INTRODUCTION

Polynuclear aromatic hydrocarbons (PAH) constitute a diverse group of several hundred organic compounds consisting of at least two fused benzene rings. From the environmental health standpoint, PAHs are important due to their mutagenicity and potential human carcinogenicity.

Soil and groundwater contaminated with PAHs have been found at numerous hazardous waste sites associated with coal gasification industries or wood preservation with creosote. PAHs are ubiquitous in nature, being formed by combustion and possibly by biosynthetic processes. Several routes exist for migration of PAHs from contaminated soil. The most important routes are runoff with subsequent deposition in a surface water body, transport in the subsurface both in dissolved form and as a nonaqueous plume and entrainment of dust contaminated with PAHs by wind. Once PAHs have migrated from a site, it is difficult to ascribe them to a particular source due to their ubiquity and the fact that individual compounds are subject to different fate and transport processes. This situation causes problems related to effectiveness of source control remedial measures; if the source is ambiguous, it is difficult if not impossible to effectively design a remedial program to control it.

BACKGROUND OF METHOD DEVELOPMENT

Although coal tar and creosote are the primary manufactured materials containing large amounts of PAHs, they have been found in virtually all media under a variety of circumstances. Table 1 presents a compilation of materials which have been analyzed and found to contain substantial quantities of PAHs.

Positive identification of any one PAH mixture is a difficult task due to the complexity of the chemical composition. Not only can a single mixture contain literally hundreds of PAHs, but there also is considerable diversity between batches. The task is further complicated by the effects of fate processes on the mixture which often result in a loss of the lower molecular weight compounds which are more volatile and more water soluble. An early attempt at a chemically definitive definition of creosote was published by the U.S. EPA.' The method involved measuring phenanthrene and carbazole in environmental samples. If the ratio of these compounds is between 1.4:1 and 5:1, the presence of creosote is indicated. Experience since the publication of this method, however, has led to the conclusion that the ratios are not reliable due to differential fate processes operating on the two compounds.

Table 1 Environmental Distribution of PAH

 Coal and Related Products Asphalt, Coal Tar, Coal Tar Pitch, Petroleum Jelly

Food

Smoked Ham, Broiled Meat, Fish, Sausage, Margarine, Spinach, Orange Rind, Sunflower Oil, Onion Peel

• Air

- Urban Air, Automobile Exhaust, Cigarette Smoke
- Soil
- Water
- Oils

Used Motor Oil, Creosote, Used Cutting Oil, Bunker C Fuel, Crude Oil

Sewage Sludge

Source: References " and 8.

One important step in the solution of the problem has been the institutionalization of the number and identities of PAHs measured in environmental media and publication of standardized laboratory techniques. Before the advent of gas chromatography/ mass spectroscopy (GC/MS) and High Performance Liquid Chromatography (HPLC) techniques, PAH analyses reported in the literature were often a function of the capabilities of the individual analyst. The net consequence of this was that results from different laboratories were not comparable. Table 2 presents a matrix of PAHs measured in various media by different laboratories. Note that these differences are not in PAHs found, but in PAHs sought. Other problems in comparability of results have involved the complex and often confusing nomenclature of PAHs in addition to the existence of a plethora of extraction and analytical techniques.

Since the publication of the U.S. EPA's priority pollutant list, most measurements of environmentally important samples have been limited to the 16 priority pollutant PAHs listed in Table 2. The U.S. EPA's hazardous substance list for Superfund contract laboratory program analysis also includes 2-methylnaphthalene among the PAHs routinely measured. Additionally, the U.S. EPA approved GC/MS or HPLC methods³ are used for the analyses, and the nomenclature used in Table 2 has been almost universally adopted. This has led to standardization across investigations and subsequent comparability of results.

Table 2						
Variation in	Analytes	Sought				

	Coal Tar (2)	Creosote (3)	Air Particulate (4)	Priority Pollutant
Napthalene Biphenyl* 2-Methylnapthalene Acenapthene Fluorene Phenanthrene Anthracene Fluoranthene Pyrene Benzo(a)fluoranthene Benzo(a)fluoranthene Benzo(b)fluoranthene Benzo(b)fluoranthene Benzo(b)fluoranthene Benzo(b)fluoranthene Benzo(b)pyrene Benzo(b)pyrene Benzo(c)pyrene Garbazole Dibenzo(ah)anthracene Perylene Dibenzo(def,mno)chrysene Naptho(1,2,3,4-def)chrysene Benzo(c)pyrene Carbazole	x x x x x x x x x x x x x x x x x x x	x x x x x x x x x x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x x x x x x x x x
Tureno (T'T'T'a-ca balene				· ^

"Not strictly a PAH, but often included in PAH analyses.

One analytical problem which has not been adequately treated by current attempts at method standardization concerns resolution of isomers and/or co-eluting compounds. At a coal tar or creosote site, each sample may consist of hundreds of PAHs. Due to their structural and physicochemical properties similarities, there is an excellent chance that some of them may co-elute from a chromatographic column. For example, in the U.S. EPA's gas chromatographic method for PAHs (Method 610), the two benzofluoranthenes are co-eluting as are three other pairs of compounds. The benzofluoranthenes also co-elute by the GC/MS method (Method 625). It is likely that other compounds also may be present but unresolved. For example, other benzofluoranthene isomers could be in the sample, however, the results may be reported only as the sum of benzo(b)- and benzo(k)-fluoranthene.

The problem is compounded by the inability of mass spectrometry to distinguish among structural isomers. In one chromatographic run with Method 625, an unknown at a retention time of 14.1 min was identified as a dimethylnaphthalene isomer. The MS library suggested 10 different isomers with quality indices from 671 to 719. It was not possible to distinguish among the different isomers or to definitively state that only one isomer was present.

During the time that standardization in PAH analysis was occurring, advances were occurring in chemometrics, especially with regard to pattern recognition and analysis of chromatographic results. A recent symposium sponsored by the American Chemical Society⁶ presented results of both chemical and statistical analyses for pattern recognition. Many of these techniques are quantitative and rely on multivariate statistical analysis. Before embarking on an application of these methods to PAHs at hazardous waste sites, it was decided to conduct a preliminary study to assess the suitability of a pattern recognition technique for environmentally important PAHs.

The technique proposed for PAH profiling involves visual comparison of patterns of histograms which describe PAH concentrations. To utilize the same scale for all measurements, it was decided to normalize the histograms with respect to the concentration of an individual PAH. Benzo(a)pyrene [B(a)P] is the PAH usually considered to be of greatest health significance and is therefore sought most frequently by analysts. For this reason, B(a)P was chosen as the compound to be used for normalization.

In general, there is good correlation among several physicochemical properties of PAHs including number of benzene rings, molecular weight, aqueous solubility and vapor pressure (Table 3). To enable the histograms to convey the maximum information (i.e., to use them in understanding environmental fate and transport), it was decided to order them on the basis of molecular weight. The histograms developed in this research thus show abundance relative to B(a)P on the ordinate and increasing molec-

		Molecular	Number of	Vapor Pressure	Water Solubility
compound	Abbreviation	Weight	Rings	(torr)	(mg/1)
Napthalene	NAP	128	2	0.0492	34,400
Acenapthylene	ACY	152	3	Not Available	3,930
Acenapthene	ACE	154	З	5×10^{-3}	3,420
Fluorene	FLU	166	3	5×10^{-3}	7,900
Phenanthrene	PHE	178	3	6.8 x 10^{-4}	1,290
Anthracene	ANT	178	3	1.9×10^{-4}	70
Fluoranthene	FLA	202	4	10-5	260
Pyrene	PYR	202	4	6.8 x 10^{-7}	140
Benzo(a)anthracene	BAA	228	4	1×10^{-7}	14
Chrysene	CHR	228	4	Not Available	2
Benzo(a)pyrene	BAP	252	5	5.5 x 10 ⁻⁹	3.8
Benzo(b)fluoranthene	BBF				
Benzo(k)fluoranthene	BKF	252	5	9.6 x 10^{-11}	0.88
Indeno(1,2,3-cd)pyrene	IPY	276	6	20-10	62
Benzo(ghi)pervlene	BGP	276	6	10-10	0.26
Dibenzo(a,b)authracene	DAA	278	5	10-10	0.5

 Table 3

 Physicochemical Properties of Priority Pollutant PAHs

ular weight on the abscissa. The method is illustrated in Fig. 1. In an effort to test the method, several samples from the literature were normalized and plotted as histograms (Fig. 2). The results show that there are clear differences among samples of coal tar, coal tar pitch, used motor oil and urban air. The results also show that there is good precision between duplicate samples. These results were sufficiently encouraging to expand the investigation to PAHs found at hazardous waste sites and to the complete suite of priority pollutant PAHs.

RESULTS

Several hypotheses were posited for testing in this portion of the investigation. The first concerned reproducibility of profiles from the same medium at the same site. Profiles of two samples of soil PAHs taken from an inactive wood treating site contaminated with creosote are shown in Fig. 3. The prifiles are quite similar for the two samples. Profiles of two samples of soil PAHs from an inactive coal gasification site are shown in Fig. 4. Again, a strong similarity is noted between the profiles. Also, there is a strong dissimilarity between the wood treating (creosote) and gasification (coal tar) samples. This result appears to confirm the second hypothesis—that there is a recognizable difference between materials of different chemical origins.

The next hypothesis tested was that of consistency between samples of similar materials from different sites. Fig. 5 shows the results of profiling PAHs from an inactive gasification site located over 1,000 miles from the previous site. Despite some variation in the two samples, it is relatively easy to recognize the similarities between these samples and the soil samples shown in Fig. 4.



Figure 1 Example of a Profile Histogram

PAHs may undergo numerous fate and transport processes in the environment. Among the various physical processes, movement of non-aqueous plumes, dissolution, sorption and volatilization are most significant. Among chemical processes, biotransformation in soil or aromatic substitutions in air are most important. The testing of hypotheses concerning fate and transport was the next stage in development of the profiling process.



Figure 2 Profiles Taken from Incomplete Literature Data



Figure 3 Examples of Creosote Adsorbed to Soil


Differences Between Liquid Adsorbed Coal Tar and Coal Tar Adsorbed to Soil

Analysis of an Unknown

The function of these hypotheses was to determine if the profiling technique accurately reflected known environmental processes undergone by PAH. Fig. 6 shows a comparison of liquid coal tar PAHs to PAHs found in site soil. The material bound to soil shows considerable attenuation in the lower molecular weight range, especially with respect to naphthalene. This result is indicative of the higher mobility or, alternatively, poorer adsorption properties of naphthalene. Supporting data are not adequate to determine the exact mechanism operating between the two samples.

Fig. 7 shows a comparison of creosote PAHs sorbed to soil and PAHs found in surface water at a creosote site. For the water samples, benzo(a)pyrene was found to be below the detection limit, so one-half the detection limit was used as the normalizing factor. The relative abundances are plotted on a natural log scale due to exceedingly high values for the low molecular weight PAHs. When viewing this figure, it should be remembered that the true values for aqueous low molecular weight PAHs are more than 100 times larger than the soil bound PAHs. Here, an enrichment of low molecular weight materials in water relative to soil may be noted. This condition probably is due to the higher aqueous solubilities of these materials.

Last, a hypothesis was formulated to test the utility of the technique as an aid in site remedial design. An investigation at a site revealed soil contamination with PAH. At another portion of the site, there was an asphalt road which had viscous uncured asphalt as part of its sub-base. Since asphalt is composed of PAHs, among other materials, it was hypothesized that the site contamination was due to the presence of improperly cured asphalt. The profiles of the unknown material, a genuine uncured asphalt sample and a coal tar sample taken from another site are shown in Fig. 8. Comparison of the profiles shows that the unknown more closely matches the coal tar than the uncured asphalt. This has obvious ramifications to site remediation. If only uncured asphalt had been present, remediation could consist of excavation of the old road. Contamination of soil with coal tar, however, indicated another source and triggered additional remedial investigation activity to define the extent of the contamination.

CURRENT AND FUTURE WORK

Several tasks are either planned or on-going to extend the utility of this work. First, numerous additional analyses are being compiled and profiled to generate a comprehensive data base. Second, methods of quantification of pattern recognition such as cluster, correlation, factor, principal component and discriminant analyses are being investigated for applicability to the method. Last, the method is being applied to other environmentally important mixtures such as polychlorinated dibenzodioxins, polychlorinated biphenyls, chlordane and toxaphene.

CONCLUSIONS

A pattern recognition technique for evaluating concentrations of PAHs found at waste sites has been developed. Preliminary results indicate that the method is reproducible, that it can discriminate between various types of PAH containing materials, and that it is responsive to environmental fate and transport processes. The method also is potentially useful as an interpretive adjunct to remedial design.

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Creep Characteristics of Drainage Nets

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ABSTRACT

Since the HSWA of RCRA were signed into law in November of 1984, drainage nets have been increasingly used as the drainage medium of choice for primary and secondary leachate collection in hazardous waste containment facilities. An area of concern in the use of plastics materials in these facilities is to what extent creep, resulting from high continuous static pressure, affects transmissivity of drainage nets over time.

Many drainage nets are available to collect leachate. They could be made from polyethylene resins of a wide variety of densities and manufactured by significantly different processes. The question then is what effect, if any, do these different resin variables have on the long-term performance characteristics of the drainage nets?

In this paper, the authors provide a comparison of drainage nets made from low, medium and high density polyethylene resins with respect to their transmissivity characteristics under load. The loads are applied to the samples for a minimum of 120 days and testing will continue for an indefinite period of time into the future (after presentation of this paper). The effect of creep on transmissivity is discussed and actual performance data are fitted to well-established mathematical models available in the literature and developed for polyethylene. These models are then used to project long-term transmissivity performance (30 years +) of drainage nets.

INTRODUCTION

The use of plastic nets to provide liquid and gas drainage in waste impoundments is finding increasingly wide-spread acceptance due to the benefits these nets provide over traditional granular materials. These benefits are both economic and performance related and are well documented.^{1,2,3}

Nets are an effective drainage medium because they have good flow properties at high static pressures and are resistant to chemical attack. They consist of two sets of crossing strands in which the strands of one set lie on top of strands of the other set forming a biplanar structure (Fig. 1).



Figure 1 Biplanar Drainage Net

The two sets of strands create two sets of channels which can carry fluids. The biplanar nature of these nets provides high fluid flow rates and permits flow even under conditions in which the channels of one set are blocked by flexible contact materials. The various types of drainage nets available can be characterized according to the following properties:

- Resin type
- Thickness
- · Density (foamed vs. unfoamed)
- Weight per unit area
- Porosity

These nets can have significantly different characteristics with respect to their ability to provide fluid flow when subjected to relatively high static pressures. Their ability to maintain the desired flow properties over time can also vary, and selection of the proper type for a given application requires an understanding of the differences among these products. The object of this research was to evaluate the flow (transmissivity) vs. creep characteristics of drainage nets primarily with respect to the first of the aforementioned properties—resin type.

MATERIALS OF CONSTRUCTION

Drainage nets generally are made of polyethylene. ASTM defines polyethylene types in terms of density as follows:⁴

Table 1 ASTM Polyethylene Classifications

Туре	Specific Gravity (Density, g/cm ³)
I	0.910 - 0.925
II	0.926 - 0.940
III	0.941 - 0.959
IV	0.960 and higher

Types I and II are referred to as low-density polyethylene (LDPE) and medium-density polyethylene (MDPE), respectively. Type III is copolymer high-density polyethylene (HDPE), and Type IV is homopolymer high-density polyethylene. Drainage nets currently available are made from Type II polyethylenes. Type III, as well as high-performance Type II resins, are made by reacting ethylene with alpha-olefin comonomers such as butene (C₄), hexene (C₆) and octene (C₈).

Drainage net physical properties are affected by the base resin chosen. Such net properties as stiffness, tensile strength, elongation, ESCR and creep resistance are dependent to varying extents upon base resin properties such as density, molecular weight distribution, melt index and comonomer type.^{4,5} In general, higher carbon comonomers produce higher performance

resins.5.6.7

For these tests, three physically similar drainage net samples were produced from each of three different resin types: I, II and III. These samples had the following characteristics:

	Te	Table 2 it Mater	lais		
baracteristics			Base	Resin Cha	racteristics
Unit Wt. Ibs/M ft ^a	Thickness (in.)	Type	Resin Density	Meli Index	Copolymer Type
135	0.160	1	0 925	0.55	homopolym
138	0.169	11	0.935	1.00	octene
136	0.167	111	0 951	0.35	hexene
	baracteristic Unit Wt. Ibs/M ft ¹ 135 138 136	Test Unit Wt. Ubs/M Thickness ft ¹ 135 0.160 138 0.169 136 0.167	Test Mater Test Mater Unit Wt. Ibs/M Thickness ft ¹ (in.) Type 135 0.160 1 138 0.169 11 136 0.167 111	Unit Wt. Trest Materials Unit Wt. Base 135 0.160 138 0.169 136 0.167	Test Materials Test Materials baracteristics Base Resin Cha Unit Wt. Karacteristics Base Resin Cha 10s/M Thickness Resin Meli ft* (in.) Type Density Index 135 0.160 1 0.925 0.55 138 0.169 11 0.935 1.00 136 0.167 111 0.951 0.35

These nets were all compounded with 2% carbon black as an additive. The samples then were subjected to 10,000 lb/ft² static pressure and periodic measurements of transmissivity were taken.

TEST EQUIPMENT

The test results presented here were obtained utilizing a uniaxial permeameter (Figs. 2 and 3).



Figure 2 Transmissivity Tester

In this method, a test specimen, approximately 4.5 in. wide by 8.5 in. long, is positioned between a top plate with an inflow tube and a base plate and then is placed in an overflow basin. The base plate arrangement directs the flow through the plane of the drainage material. For this test program, the prefabricated drain extended to the front of the inflow port. Therefore, flow could occur through the full drain simulating field conditions. This long-term test was subjected to 10,000 lb/ft² normal load by loading the top plate with air pressure diaphragms.



TEST PROCEDURE

The samples were cut to dimension and placed in the test device.[•] Edges parallel to the flow were caulked to prevent leakage around the net. The top plate was then put in place and the edges were caulked. A pneumatic diaphragm was installed above the plate. Above this, another metal place was bolted in place to restrain the diaphragm. The tester was then placed in a water basin to provide a reference water level.

•Tests conducted by STS Consultants, Ltd., Northbrook, Illinois.

The tester was filled with water, the diaphragm was inflated to provide a 10,000 lb/ft^2 load and constant head transmissivity tests were run immediately. Tests were run at gradients of 0.25 and 1.5. Subsequent tests were run after 1, 2, 4, 8, 16, 30, 60 and 100 days under load.

(1)

TRANSMISSIVITY CALCULATION

Transmissivity values were calculated as follows:

 $\theta_{\tau} = \mathbf{Q} / \mathbf{B} \cdot \mathbf{i}$

where:

 θ_{τ} = Transmissivity at the test temperature

- τ (cm³/sec/cm)
- B = Width of the sample (cm)
- i = Gradient (dimensionless)
- Q = Volumetric flow rate (cm³/sec)

Sample temperature was maintained at ambient conditions of about 20 °C so no temperature corrections were applied.

EXPERIMENTAL RESULTS

Results obtained are displayed in Figs. 4(a-f). Results are provided for two different hydraulic gradients (0.25 and 1.50) for each of the 3 resin types tested.

Resin type III showed a rapid decline in transmissivity beginning approximately 10 days (250 hours) after the tests were initiated. The rate of decline stabilized somewhat after 105 days, and the test was terminated to permit examination of the sample (Fig. 5).

The strands of the sample were found to be laid over from ther original vertical alignment (Fig. 1) which decreased the sample's effective thickness significantly. In addition, most of the junctions at which the upper layer of strands crossed the lower layer of strands were fractured or cracked. The strands themselves, however, appeared to be undamaged.



Figure 4 Results of Transmissivity vs. Time Tests Performed on Type I, II and III Polyethylenes at 10,000 lb/ft²



Figure 5 Type III Polyethylene Net After 105 Days at 10,000 lb/ft² Normal Stress

DISCUSSION

Several mathematical model types are available in the literature to which long-term compression creep data can be fitted.^{8,9} These are generally power-law models of the type:

$$\epsilon = \epsilon_0 + m t^n \tag{2}$$

where:

E = strain

t = time

 ϵ_0 09 and m = constants for constant stress

Findley and Tracy⁸ report good agreement of this model with data obtained for polyethylene after 132,000 hrs (\sim 16 years). Rearranging Equation 2 and taking the logarithms of both sides yields:

$$\log(\epsilon - \epsilon_0) = \log m + n \log t$$
(3)

Equation 3 represents a straight line with log ($\epsilon - \epsilon_0$) as ordinate, log t as abscissa and n as the slope of the line.

Values for these constants can vary within a fairly well documented range for various polyethylenes.^{8,10,11,12} A typical set of values is shown in Table 3.

 Table 3

 Evaluation of ϵ_0 , m and n in Equation 1 for Compressive

 Creep Tests of Polyethylene at 75 °F.

 (From O'Connor and Findley'')

S.G	Mi	MWn	€0 %	m‰	n	σ (lb/in. ²	
0.924	1.2	22,000	- 0.40	0.810	0.0208	75	
0.924	1.2	22,000	-0.80	1.657	0.0208	100	
0.924	1.2	22,000	- 1.20	2.498	0.0208	225	
0.924	1.2	22,000	- 1.80	3.578	0.0208	300	

Figure 5

Type III Polyethylene Net After 105 Days at 10,000 lb/ft2 Normal Stress

An estimate for the compressive creep of polyethylene at the end of 262,000 hours (\approx 30 years) at a stress of 300 lb/in.² using these constants in Equation 1 yields:

$$\epsilon = -1.80 + 3.578 (262,000)^{0.0206}$$

= 2.83%

Findley⁹ and others have proposed a modification of this model which yields somewhat different results where ϵ_0 and m are hyperbolic sine functions of stress σ and are expressed by:

$$\epsilon_{\rm O} = \epsilon_{\rm O}^{\rm I} \sinh\left(\sigma/\sigma_{\rm e}\right) \tag{4}$$

 $m = m^{1} \sinh \left(\sigma / \sigma_{m} \right)$ ⁽⁵⁾

where ϵ_0^{l} , m^{l} , σ_e and σ_m are constants of the material. Equation 2 can be written to incorporate Equation 4 as follows:

$$\epsilon = \epsilon_0^4 \sinh(\sigma/\sigma_e) + m^4 \tan \sinh(\sigma/\sigma_m)$$
(6)

This equation shows good agreement with experimental results in describing the compressive creep of polyethylene.⁹

The constants for this equation are reported by Findley and Khosia⁹ for polyethylene as follows:

	4						
Constants	of Compr	essive (Creep	Equation	1 4 for	Poly	ethylene
$a_{\rm b} = 2$	_			Le r.	- 46 /-		<i>a</i> . <i>c</i> . b .

$\sigma(lb/in.^2)$	<u>n</u>	eto %	m*%	σe(lb/in.2)	<u> σm(lb/in.2)</u>
75-300	0.0208	- 1.522	4.60	300	425

Using Equation 6 to estimate compressive creep for polyethylene at the end of 262,000 hours and at a stress of 300 lb/in.² rsults in the following:

 $\epsilon = -1.522 \sinh (300/300) + 4.60 \sinh (300/425)$ = 1.72%

The stresses encountered by a polyethylene net at $10,000 \text{ lb/ft}^2$ (69.4 lb/in.²) can be higher than expected. Since the pressures encountered are borne completely at the junctions where the strands cross over, the (initial) static pressures can be as high as 1500 lb/in.², depending upon the specific strand and junction dimensions of the product.

Hydrostatic compressive creep data for polyethylene¹⁰ has been generated at pressures as high as 50,000 lb/in.² which provides some basis for extrapolating data provided in Table 3.d Using this approach to estimate ϵ at $\sigma = 1500$ lb/in.²:

$$\epsilon (\%) = \epsilon_0 + m t^n$$
(7)

$$\epsilon (\%) = -3.06 + 6.15 t^{0.0208}$$
(7)

where to and m are extrapolated values from Table 3.

While there is some variation in the available compression creep data, work done to date in this area suggests that the compressive creep component of the various factors contributing to thickness loss in drainage nets should be <10% of the original thickness over a 30-year period at the considered static pressures.

Regression analysis of the data in Figs. 4 (a-f) provides coefficients for the model in Equation 2 which predict substantially greater thickness losses over a 30-year period than can be accounted for by compressive creep considerations alone—especially in the cases of the Type 1 (4 a,b) and Type III (4 e,f) polyethylenes.

For example, using the data in Fig. 4a, regression analysis yields the following model (for transmissivity, θ):

$$\theta = \theta_0$$
 'm in. thin. (8)

$$\theta = 6.90 - 1.585 \text{ t}^{-0.140}$$

This model predicts that the transmissivity of the Type 1 polyethylene reaches zero at approximately 35,000 hours (3¹/₂ years).

It became apparent during the testing program that compressive creep was not the only (or, in some cases, even the major) source of thickness loss. Models such as Equation 8 are meant to fit compressive creep data only. Non-creep factors which bias the coefficients of these models can lead to incorrect conclusions when extrapolated.

As previously shown in Fig. 5, the strands in the post-test type III sample were laid over resulting in a net structure in which the overall thickness was primarily a product of the strand width rather than the strand height. The thickness loss (and thus the transmissivity loss) exhibited in the type III sample is the sum resulting from three separate sources of thickness loss:

- Initial compression
- Compressive creep
- Strand layover

These sources of thickness loss can be quantified best by using the following technique on the type III sample since this sample clearly underwent strand layover during the test.

SAMPLE CALCULATION

initial Compression

Actual strain gauge measurements are used to obtain initial compressive strain data for the type III net sample, for example at z = 0.01 days:

Initial strain = 0.031 in. =
$$\epsilon_{.01}$$

T₀ - $\epsilon_{.01}$ = 0.167 in. - 0.031 in.
= 0.136 in. = T_{.01}

where $T_{.01}$ (subscripts in days) is the thickness from which the initial transmissivity is taken (Fig. 4e). Therefore, there is a thickness loss from T_0 of 0.031 in./0.165 in. = 0.186 or 18.6% which is a function of the initial compressibility (or compressive resistance) of the sample. Note, however, that the initial transmissivity $\theta_{.01}$ is measured at the $T_{.01}$ datum.

Compressive Creep

The compressive creep thickness loss component at 105 days (2520 hrs) can be computed using Equation 2 and the extrapolated values from Table 3 (for 1500 lb/in.² static pressure):

$$\epsilon = -3.06 + 6.15 (2520)^{0.0203}$$

= 4.17% of $T_0 = 0.007$ in.



Figure 6 Transmissivity Retention vs. Thickness at i = 0.25

Strand Layover

Direct measurement of the strand width yields the following result:

Top =
$$0.067$$
 in.
Bottom = 0.057 in.
 0.124 in.

(This value also can be approximated by a calculation which uses the strand count, density, thickness and unit weight of the net.)

When laid over, the net thickness is the product of the sum of the strand widths and the compressibility. (Ideally, this calculation should be corrected to reflect reduced pressure due to increased strand contact area when laid over). Our measure of compressibility is:

 $(T_0 - \epsilon_{.01})/T_0 = (0.167 \text{ in.} - 0.031 \text{ in.})/0.167 \text{ in.} = 0.814$

Thus the approximate thickness after layover is:

(0.124 in.) (0.814) = 0.101 in.

The total thickness after subtracting the compressive creep component is:

0.101 in. - 0.007 in. = 0.094 in.

and as a percentage of T_0 :

0.094 in. / 0.167 in. = 0.563 or 56.3%

The total thickness loss from T_0 due to initial compression, compressive creep and strand layover is, therefore, 100% – 56.3% = 43.7%. Using Fig. 6, one would predict a transmissivity retention (θ_{105}/θ_0) of 22% after 105 days (2500 hours).

The initial transmissivity of this sample was measured at time $t_{.01}$ which corresponds to a thickness loss of 18.6%, as previously discussed, and from Fig. 6:

$$\frac{\theta_{.01}}{\theta_{0}} = 0.78$$

Therefore the actual transmissivity retention ratio at 105 days (Fig. 4e)

$$\frac{\theta_{105}}{\theta_{01}} = \frac{106}{4.14} = 0.26$$

corresponds to a base transmissivity retention ratio of:

$$\frac{\theta_{.01}}{\theta_{.01}} \bullet \frac{\theta_{.105}}{\theta_{.01}} = (0.78)(0.26) = 0.20$$

or 20% which is in good agreement with our predicted results.

One can also project that the transmissivity at 262,000 hours (30 yrs) will be reduced from this level by compressive creep strain only (since strand layover of this sample has obviously occurred):

$$(\%) = -3.06 + 6.15 (262,000)^{0.0208}$$

= .0491\%

The thickness loss due to creep strain is, therefore:

 $(0.0491) \times (0.167 \text{ in.}) = 0.008 \text{ in.}$

which is an additional (0.008 in. - 0.007 in. =) 0.001 in. from the 105-day value. The total thickness after subtracting the 30-year creep component is now:

0.101 in. -0.008 in. =0.093 in.

and as a percentage of T_o:

0.093 in. / 0.167 in. = 0.557 or 55.7%

The 30-year (10,950 day) thickness loss from T_0 due to initial

compression, compressive creep and strand layover for the type III sample is projected to be 100% - 55.7% = 44.3%.

Using Fig. 6, one would predict a base transmissivity retention $(\theta_{10,950}/\theta_0)$ of approximately 19% after 30 years (Table 5). This is approximately equivalent to a transmissivity retention of 24% of the initial transmissivity measurement taken at 10,000 lb/ft².

Table 5					
Projected	VS.	Actual	Transmissivity	Retention	

Type III Sample Actual				To = 0.167 is Projected			
Time (days)	T(in)	0i/0.01	01/80	T(in)	Øi/Ø.01	0i/80	
initial	0.167		- P				
0.01	0.136		0.78		****		
± 105		0.26	0.20	0.094	0.28	0.22	
± 10,95 0		N/A	N/A	0.093	0.24	0.19	
(30 yrs)							

* after strand layover

It is apparent from the strand layover calculations that increasing the strand width will have a significant effect on increasing the 30-year transmissivity in a layover condition. Of course, such a product is also less likely to undergo such a layover.

It would be premature to extrapolate the performance potential for the Type I and II resins because of the uncertain status of the relative components of strand layover and compressive creep in making up the model. The Type II polyethylene appears to substantially out-perform the Type I resin up to 2500 hours (105 days), however. Note that the Type II 100-day transmissivity retention ratio $(\theta_i/\theta_{.01})$ is in excess of 80% (Fig. 4c,d).

Tests are presently underway to more accurately identify the model coefficients with respect to:

- Resin type
- · Comonomer type
- Specific resin properties such as tensile, modulus, compressive resistance, etc.

CONCLUSIONS

The factors which cause a drainage net to lose thickness and, therefore, transmissivity are:

- Initial compression
- Compressive creep
- Strand layover

Compressive creep appears to be a relatively small contributor to overall thickness loss at the stress levels considered relative to other sources of thickness loss, however.

A significant potential source of performance loss is strand layover. Problems in this area can be avoided by:

- The selection of properly designed drainage nets
- The use of nets which have a significant margin of safety at the targeted stress levels. (The nets evaluated in these tests are on

the lower performance end of products available, whereas the pressures evaluated are on the higher end of pressures commonly encountered in these applications.)

Low compressibility (i.e., high compressive resistance) is a desirable feature in a drainage net to minimize initial compression as long as it does not result in a brittle product prone to fracture. However, a drainage net which does suffer layover and even joint fracture apparently will continue to function, albeit at a lower level of efficiency.

Data of this type are not easily extrapolated because of the dynamic nature of the transmissivity versus time plot. Component modelling is probably a more accurate way to predict drainage net behavior. In any event, tests of this type should be conducted for periods of time greater than 120 days to facilitate trend identification.

Finally, although this testing was conducted at room temperature (approximately 20 °C), the application temperature for these products may be on the order of 10 °C lower. This would tend to reduce any error in the estimation of strain due to compressive creep which may be present in this analysis.^{13,14}

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Innovative Engineered Systems for Biological Treatment of Contaminated Groundwater

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ABSTRACT

Improved biotreatment techniques represent an economical and effective means of complying with new environmental legislation calling for control of toxic and hazardous organic and inorganic substances. Microbiological research has expanded knowledge of the biotreatability of complex organics. By combining this knowledge with innovative reactor design concepts, Dorr-Oliver has developed efficient engineered systems for treatment and detoxification of contaminated water and wastes. The systems are based on the aerobic and anaerobic biological fluidized bed and membrane biological reactor concepts. Physicalchemical mechanisms for contaminant removal are an inherent part of the systems or can be integrated readily into the systems. This paper describes the technologies and their benefits in treating complex organics, discusses the technical and economic factors dictating system selection and presents application information.

INTRODUCTION

Improved biotreatment techniques represent an economical and effective means of complying with new environmental legislation calling for control of toxic and hazardous organic and inorganic substances. Extensive research work at the government and university levels and, to a lesser degree, by private industry has expanded knowledge of microbial detoxification and/or degradation of complex organics. In 1985 the U.S. EPA was involved in the management of biotechnology research projects such as biodegradation of 2,4-D, microbial dechlorination and aerobic degradation of trichloroethylene.

Wastewaters normally are composed of a complex matrix of various concentrations of compounds. These compounds may be degradable, inhibitory or recalcitrant to various degrees. Physical-chemical treatment techniques may be required in order to render the wastewater less inhibitory to microbial treatment or ensure the removal of non-biodegradable compounds. Physicalchemical treatment normally is provided by the addition of unit processes before or after the biological step. Integration of these removal mechanisms into the biological step represents a costeffective treatment alternative if technically feasible.

Dorr-Oliver has developed efficient engineered systems for treatment and detoxification of contaminated water and wastewaters by combining the knowledge gained from biotechnology research with innovative reactor design concepts. The systems the company has developed are based on aerobic and anaerobic fluidized bed and membrane biological reactor concepts. Physicalchemical mechanisms for contaminant removal are an inherent part of the systems or can be integrated readily into the systems. It is the purpose of this paper to describe the technologies and their benefits in treating complex organics, discuss the technical and economic factors dictating system selection and present application information.

FLUIDIZED BED AND MEMBRANE BIOREACTOR TECHNOLOGIES FOR TREATMENT OF COMPLEX ORGANICS

The biological process reactors available for wastewater treatment can be classified according to the nature of the biological growth in the system. Those reactors in which the active biomass is suspended as free organisms or microbial aggregates can be regarded as suspended growth reactors, whereas those in which growth occurs on or within a solid medium can be termed supported growth or fixed-film reactors.

The fluidized bed reactor represents a highly efficient fixed-film reactor in which biomass build-up occurs on an inert (sand) or active (activated carbon, resin material, etc.) fluidized support medium high in external surface area. The principles of the fluidized bed process have been incorporated into full-scale aerobic and anaerobic configurations through the development of the Oxitron[®] and AnitronTM systems, respectively.

In the fluidized bed process (Fig. 1), the contaminated wastewater and recycled effluent pass upward through the medium at a velocity sufficient to expand the bed beyond the point at which the frictional drag is equal to the net downward force exerted by gravity. Once at or beyond this point of minimum fluidization, the particles that make up the bed are individually and hydraulically supported. These particles provide a large surface area for biological growth, in part leading to the development of a biomass concentration approximately five to ten times greater



Figure 1 Oxitron System Process Schematic

than that normally maintained in a suspended growth system, consequently reducing the required liquid contact time or hydraulic retention time (HRT).

The fluidized bed bioreactor is extremely simple in design, contains a piping to distribute the influent flow and has a component to control the expansion of the fluidized bed. When biological growth occurs on the fluid bed medium, the effective diameter of the medium support particle increases and its effective density decreases, resulting in an expansion of the fluidized bed beyond that due to fluidization of the unseeded medium. It may be necessary to control the biofilm thickness to prevent the density of the biofilm-covered medium (bioparticle) from decreasing to the point where bed carryover occurs. This control is accomplished by monitoring the bed expansion optically, carrying out separation of the medium from the biomass if the maximum specified bed height is reached and returning the medium to the reactor.

The maintenance of a highly active biomass in a suspended growth reactor is dependent on the performance of the downstream solid-liquid separation step and subsequent cell recycle. The membrane bioreactor represents an advanced suspended growth reactor in which a high active microbial concentration (12,000 to 30,000 mg/l volatile suspended solids) is achieved through the use of ultrafiltration for biomass-effluent separation and subsequent recycle to the biological reactor. Commercial embodiments of the concept in aerobic (Fig. 2) or anaerobic configurations are represented by the Membrane Aerobic or Anaerobic Reactor System (MARSTM).



Figure 2 Aerobic MARS Process Schematic

The fluidized bed and membrane bioreactors will be most attractive when the benefits of the systems can be realized due to qualitative and/or quantitative characteristics of the wastewater in question. The Oxitron/Anitron and MARS concepts overcome many issues of concern in applying microbial methods for treatment of hazardous wastewaters (Table 1).

Situations which require rapid treatment of the organic contaminants will favor these technologies versus alternative biological systems. Microbial detoxification and/or degradation of complex organics normally require the maintenance of a long solids retention time (SRT) or cell residence time corresponding to a slow net specific growth rate of the organisms in question. Accumulating a large biomass concentration in the fluidized bed or membrane bioreactor allows efficient removal of complex organic compounds at a short liquid contact time or HRT relative to more conventional suspended growth (activated sludge, sequencing batch reactor, aerobic/anaerobic lagoons) and fixed-film (downflow or upflow packed bed reactors) systems.

The fluidized bed and membrane bioreactors allow selective development and reliable retention or microbial populations effective against specific complex compounds. The fluidized bed

Table 1 Issues of Concern in Biotreatment of Hazardous Waters and Wastewaters Addressed by Fluidized Bed and/or Membrane Bioreactor Concepts

ISSUE	SOLUTION
Efficient treatment.	Long solids retention times (SRTs) can be achieved in fluid bed and annorane bioreac- tors at short liquid contact times.
System upsets due to loss of reactor biomess (changing bio- mess settling characteris- tics).	Use of membrane bioreactor provides absolute control of biomass faventory. Fized-file nature of fluid bed bioreactor minimizes con- cern.
Build-up and retention of biomass in treatment of wasta streams low in con- taminant concentration,	Absolute biomass investory control in man- brame bioractor still allows maintenance of required SRT for treatment. Fixed-film ma- ture of fluid bed allows build-up/retestion of biomass.
Treatment of slowly degrad- able or recalcitrant com- pounds.	Characteristically long SRTs and use of gran- ular activated carbon in fluid bed or pou- dered activated carbon in mumbrane bioreactor provide maximum opportunity for treatment.
System upsets due to micro- bially toxic/inhibitory feed inputs.	Eliminated or minimized in fluid bed and mem- brane bioreactor by characteristically long SRTs and optional use of activated carbon. High effluent recycle in fluid bed provides faed dilution. Complete-mix nature of mem- brane bioreactor disperses taxicant.
Stripping of volatile organics and creation of aerosols.	Application of $0x$ itros with use of bigb purity 0_2 and pre-dissolution eliminates stripping.
Disposal of excess biomoss (sludge or other residuals) and associated (sorbed) contaminants.	Characteristically long SRTs result in mini- mal excess biomass production. Bioregenera- tion of carbon minimizes its replecement when used as media in fluid bed or when added is powdered form to membrane bioreactor.

achieves this microbial retention through development of a biofilm. A certain amount of uncontrolled biomass is lost from all biofilm reactors; this loss is minimal in the fluidized bed reactor since the design of the Oxitron/Anitron systems provides for control of biofilm thickness.

Biomass loss must be less than the rate of growth of new biofilm. Since the rate of growth of new biofilm declines as the concentration of the contaminants of concern declines in the reactor, the biofilm reactor may lose its efficiency and the reactor HRT may have to be increased in order to maintain the required SRT. The MARS bioreactor achieves a large biomass density by absolute and controlled retention of all developed microorganisms. The SRT can be controlled precisely by removal of excess biomass directly from the reactor (Fig. 2). Precise SRT control prevents the loss of specially selected microorganisms having the capability to remove a specific compound or grow efficiently at very low contaminant concentrations.

The characteristically long SRTs attainable in the fluidized bed and membrane bioreactors minimize the changes of inhibition due to microbially toxic or inhibitory feed inputs. Tolerance to such conditions can be further achieved by promotion of physical-chemical adsorption through the use of granular activated carbon (GAC) as the fluidizing medium in the fluidized bed reactor and/or the addition of powdered activated carbon (PAC) to the membrane bioreactor. The use of activated carbon in the bioreactors provides additional benefits including more rapid initial removal upon startup and a greater removal of slowly degradable or recalcitrant compounds. Upon reactor startup, the activated carbon removes these materials from the wastewater, concentrating them on the carbon surface. With microbial growth, biodegradation becomes an important removal mechanism in addition to extending the life of the carbon through bioregeneration.

Activated carbon in a biological reactor should reduce the vola-

tilization of adsorbable compounds. Operation of the aerobic MARS concept using pure oxygen as the source of oxygen, with or without the addition of PAC, would reduce air stripping of volatile organic compounds (VOCs) relative to conventional aerobic systems. The Oxitron system represents the optimal choice in situations where environmental constraints dictate that VOC stripping must be minimized. In the system (Fig. 1), required oxygen is dissolved in the influent stream prior to entry into the fluidized bed in a controlled fashion to ensure no excess oxygen is released at the top of the reactor. The use of high-purity oxygen and predissolution ensures little or no release of volatile organics into the atmosphere.

SYSTEM SELECTION

Selection of the fluidized bed or the membrane bioreactor for treatment of a specific wastewater stream is dictated by both technical and economic factors (Table 2). Although the mass organic loading (flow multiplied by concentration) is a key factor when determining the size of the biological reactors, the size of the ultrafiltration unit of MARS is directly dependent on flow rate. Consequently, relative to Oxitron/Anitron, this system is often more cost-effective for treatment of lower volumes of wastewaters.

Hazardous wastewaters containing degradable organic suspended material and emulsified oil and grease are handled more readily in MARS. The use of ultrafiltration for biomasseffluent separation and subsequent cell recycle ensures retention of such materials and subsequent biodegradation provided the organisms responsible for their removal have growth rates equal to or greater than the inverse of the SRT maintained in the biological reactor.

The characteristics of the specific soluble organics contained in a hazardous wastewater stream in terms of biodegradability, adsorbability and volatility determine the applicability of the fluidized bed and/or the membrane bioreactor systems with or without the use or addition of activated carbon. Examples of complex soluble organics treatable in aerobic versions of these systems are provided in Table 3.

 Table 2

 Factors Governing Selection of Fluidized Bed versus Membrane

 Biological Reactor in the Treatment of Hazardous Wastewaters

FACTOR	FLUID BED BIOREACTOR (UXITRON/ANITRON) VERSUS MEMBRANE BIOREACTOR (MARS)
Effluent quality.	Nembrane bioreactor normally will provide better effluent quality as effluent will contain no sus- pended solids.
Treatment of highly volatile organics.	Little or no volatilization/stripping of organics will occur in Oxitron. More volatilization nor- maily will occur in MARS.
Treatment of particu- late and soluble organics.	Particulate organics are handled better in NARS due to retention by ultrafiltration component and subsequent biotreatment. Fluid bed and membrane bioreactor both handle soluble organics efficient- ly.
Economics.	Fluid bed is often more cost effective than MARS in treatment of "high" volume water and waste- waters.
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The anaerobic versions of the fluidized bed and the membrane bioreactor systems may be attractive in situations where it is anticipated that the treated effluent will be disposed of in a municipal treatment plant. Treatment of a leachate from a landfill is an example where anaerobic pretreatment may be a more cost-effective solution than aerobic treatment. Alternatively,

 Table 3

 Examples of Complex Organics Treatable in Aerobic Fluid Bed or Membrane Bioreactor Systems

SYSTEM	CHARACTERISTICS OF APPLICABLE COMPOUNDS	EXAMPLE
Oxitron or aerobic MARS	Aerobically biodegrad- able and not readily volatilized	Phenol, Acrylonitrile, Hexa- chloroethane
Oxitron	Aerobically biodegrad- able and volatile or semi-volatile	Carbon tetrachloride, Naptha- lene, Ethylbenzeme, Toluene, Benzene, Methylene chloride, Methyl ethyl ketone
Oxitron with carbon as fluid bed media	Not readily aerobically biodegradable, volatile or semi-volatile, and absorbable on carbon	Trichloroethylene, Tetrachloro- ethylene, 1,2-dichlorobenzene
Oxitron with carbon as fluid bed media or aerobic MARS with carbon addition	Not readily aerobically biodegradable, not readi- ly volatilized but ab- sorbable on carbon	1,2,4 trichlorobenzene, Bis- (-ethyl hexyl) pthalate, Penta- chlorophenol

series operation of anaerobic and aerobic fluidized bed or membrane bioreactors may be the most attractive flow scheme, depending on the specific organics contained within the wastewater and the degree of treatment required.

APPLICATIONS

To date, mobile/transportable and permanently installed Oxitron/Anitron and MARS systems have been used for the treatment of a number of wastewater streams containing a variety of toxic organics and inorganic compounds. Example applications are listed in Table 4.

 Table 4

 Applications to Date of Dorr-Oliver's Biological Systems to Treatment of Toxic Organic Wastewaters

SOURCE	TYPE OF CONTAMINANTS
Automotive Industry	
Paint solvents	Volatile organic compounds
- Metalworking fluids	Petroleum-based hydrocarbons, glycols, amides, amines, ethers
Chemical/Petrochemical Industry	
 Process water from synthetic fiber pro- duction 	Acrylonitrile and other organics
011 refinery process wastewater	Methyl ethyl ketone, toluene, methyl pyrrolidon and other organics
Synthetic Fuels	
 Shale oil processing wastewaters 	Polycyclic organics, ammonia, organic sulfides, etc.
- Coal liquefaction process wastewaters	Phenols, ammonia, organic nitrogen compounds and other organics
Iron and Steel Industry	
Coke plant wastes and blast furnace blowdown	Phenols, polyaromatic hydrocarbons, ammonia, etc.
Pulp and Paper Industry	
<pre>XSSC corrugating mill and hardboard mill wastewaters</pre>	Organic acids, alcohols, sulfur com- pounds, etc.
 Sulfite mill conden- sates 	Acetic acid, methanol, furfural, ammonia, sulfur compounds, etc.

Applications of the technologies for nitrate and nitrite-nitrogen removal from groundwater and river water have not been included in Table 4. These compounds normally are not considered toxic, although they can give rise to serious health issues. High nitrate levels in drinking waters have been associated with methaemoglobinemia in infants and may influence human cancer incidence through the formation of nitrosamines. Three of the 11 Dorr-Oliver fluidized bed commercial installations involve the application of the technology for nitrate removal. One system is located at a municipal water treatment plant and is designed to treat up to 1 mgd of river water containing approximately 15 mg/l of nitrate-nitrogen. The fluidized bed reactor of the system consists of a 5.2 m² rectangular tank 3.5 m high. A smaller transportable fluidized bed reactor was operated at an industrial site treating groundwater containing up to 60 mg/l of nitratenitrogen. The nitrogen originated from the use of sodium nitrate in the manufacturing of rubber trim for the automotive industry. Nitrate-nitrogen reductions greater than 90% were achieved at a fluidized bed liquid contact time of less than 45 min.

Additional information derived from other applications of the technologies follows.

Contaminant Source: Automotive Manufacturing

The painting of automobiles and light-duty trucks at assembly plants has been identified by the U.S. EPA as a significant source of volatile organic compound emissions. VOC emissions can be reduced by process changes such as using water-based coatings or powder coatings; however the change may not necessarily be costeffective. Carbon adsorption and incineration of airborne VOCs are feasible control techniques, but again at very high costs.

Recently, a major automotive company completed an in-depth study of options for controlling VOC emissions from paint spray booths. It was demonstrated that significant portions of the VOCs can be removed by existing Venturi scrubbers in the paint spray booths and then biologically degraded in the Oxitron aerobic fluidized bed system. The effluent from the biological system was subsequently recycled to the paint booth to allow for further VOC uptake (Fig. 3).



The fluidized bed reactor of the biologically based VOC control system consisted of a 17.8 m^2 rectangular tank. The reactor was 5.0 m high and had a total organic carbon loading capacity of 2.8 kg/day. The fluidizing medium utilized in the reactor was quart-zite sand.

Variable concentration levels of a wide variety of organic carbon compounds were measured in the feed to the fluidized bed reactor including methanol, acetone, methyl chloride, isopropyl alcohol, 1-propanol, methyl ethyl ketone (MEK), benzene, toluene, 1-butanol and cyclohexanone. A performance assessment indicated that little or no volatilization of the organics occurred in the biological reactor. Although the efficiency of the VOC control system depended on achieving a high volumetric VOC removal rate (kg VOC/m³-day) versus a high percent VOC reduction, percent removal information was determined for certain compounds at a relatively constant feed rate to the reactor. The results (Table 5) were not derived under controlled conditions and, therefore, only reflect the potential performance of the Oxitron system in this application.

Contaminant Source: Petroleum Refining

The process wastewater from a Pennsylvania petroleum refiner is treated in an on-site facility that uses flow equalization, free oil removal, chemical emulsion breaking, flocculation and dissolved air flotation. This conventional oily wastewater treatment scheme was not able to achieve compliance with permit requirements during spills of methyl ethyl ketone (MEK), toluene and N-methyl-2pyrrolidon (NMP), compounds used in the dewaxing and extraction unit processes associated with the manufacture of high quality lubricants. A transportable Oxitron unit was tested to determine its ability to handle the effluent from the oily wastewater treatment plant during permit excursions associated with MEK, toluene and NMP spills. The unit was operated under normal feed conditions and then subjected to shock inputs of these organics.

The results in Figure 4 are representative of the performance of the Oxitron system under such conditions.

 Table 5

 Results Indicating Performance Potential of the Oxitron System in the Treatment of Paint Solvents

COMPOUND	HARINUM FEED Concentration, mg/ L	HININUM EFFLUENT Concentration, mg/1	APPROXIMATE FLUIDIZED REACTOR HITT ¹⁾ , h
Benzene	116.8	15.9	4
1-butano1	84.2	4.1	4
Acetone	28.1	0.5	4
Nethyl ethyl Letone	5.6	0.7	٠
[sopropy] alcoho]	9.5	0.5	4

Note:

1) Based on volume occupied by fluidized bed.

The aerobic fluidized bed produced an effluent biochemical oxygen demand (BOD_5) of approximately 10 mg/l prior to a shock loading of MEK and toluene (Fig. 4). Although the shock loading resulted in the feed BOD₅ increasing from approximately 60 to 220 mg/l, the impact on the effluent from the fluidized reactor was relatively insignificant. These results illustrate the ability of the Oxitron system to absorb shock loads of complex organics.

Contaminated Source: Metalworking Operations

Major segments of the metalworking industry are converting from petroleum and oil-based coolants used for machining and hydraulic applications to synthetic and semi-synthetic coolants. The synthetics are based on water soluble organics such as complex glycols, amines, amides, esters and fatty acids. A major concern relating to the use of synthetic coolants for the industrial user is the incompatibility of the compounds with existing on-site wastewater treatment systems. The true synthetic coolants contain no petroleum oil, thus the organics are completely water soluble and normally cannot be separated from the water phase as can the oil by breaking the oil-water emulsion. Therefore, the conven-



Figure 4 Response of Oxitron System to Shock Loading of MEK and Toluene

tional oily wastewater treatment system will not effect removal of the soluble organics, and the plant effluent will contain significant levels of BOD_5 , chemical oxygen demand (COD) and organic nitrogen compounds.

In 1984 and 1985, General Motors' Hydramatic plant in Ypsilanti, Michigan, conducted extensive pilot studies involving the Oxitron system. On the basis of the results of those studies, a fullscale Oxitron system is being installed at the Hydramatic plant for the treatment of the effluent from the conventional oily wastewater treatment system. The pilot plant results indicated that, although a 98% BOD₅ reduction could be achieved in the Oxitron system, a large fraction of slowly biodegradable or recalcitrant organic carbon limited the COD removal to an effluent level of approximately 450 mg/l. A study currently is being completed to assess the capability of Oxitron and aerobic MARS reactors operating in parallel to reduce this COD level.

The fluidized bed reactor contains granular activated carbon as the fluidizing medium, and powdered activated carbon is being added to the MARS reactor. Combined biodegradation and physical-chemical adsorption is expected to result in a significant degradation of this slowly biodegradable/recalcitrant organic material. Preliminary results indicate that the systems can reduce the COD level to less than 80 mg/l.

CONCLUSIONS

Dorr-Oliver has developed efficient engineered systems for treatment and detoxification of contaminated wastewaters. The systems are based on the aerobic and anaerobic biological fixedfilm fluidized bed (Oxitron/Anitron) and membrane suspended growth biological reactors (MARS). Physical-chemical mechanisms for contaminant removal are an inherent part of the systems or can be readily integrated into the systems.

The Oxitron/Anitron and MARS systems overcome many concerns in applying microbial methods for treatment of hazardous wastewaters. The systems: provide high volumetric efficiency and maximum opportunity for treatment of slowly biodegradable or recalcitrant compounds; can withstand microbially toxic/inhibitory feed inputs; allow treatment of volatile organics with little or no stripping; and result in the production of minimal residual byproducts (excess biomass or other residuals). Examples of complex organics treatable in one or more of the systems include toluene, methyl ethyl ketone, naphthalene, trichloroethylene and pentachlorophenol. To date, mobile/transportable and permanently installed Oxitron/Anitron and MARS systems have been applied for treatment of a variety of toxic organic and inorganic compounds.

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Horizontal Drilling Beneath Superfund Sites

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ABSTRACT

As a result of new drilling techniques, horizontal radial wells can now be remotely placed from a central vertical well. This new technology potentially has numerous applications to hazardous waste problems. This paper describes the methods by which such horizontal wells (radials) are emplaced and discusses potential applications in remediation and monitoring of hazardous waste sites.

Current conventional methods for groundwater control rely on placement of numerous vertical drill holes and wells for the characterization, monitoring and remedial action phases of site studies. There are limitations and inherent difficulties with vertical wells, such as surface access and potential cross-contamination of aquifers. Horizontal well placement techniques may provide viable solutions to these limitations.

INTRODUCTION

Horizontal wells have been used for decades in a limited way. Traditional horizontal well drilling methods include hillside drains and collector radials from large diameter wells. These methods are either limited in application by terrain or require human miner access downhole. In the oil industry, deviated drilling from the vertical to the horizontal is available with large radius of curvature (1800 to 3000 ft) or with medium radius of curvature (20 to 40 ft). Two major limitations of large and medium radius deviated drilling are that: (1) only one radial may be placed in each vertical well, and (2) the horizontal wells cannot be placed at a precise level. Such precise placement requires curvature from vertical to horizontal via a small radius turn. The recent development and commercialization of a novel high pressure, hydraulic jet drilling system by Petrolphysics and Bechtel now allows the placement of multiple horizontal radials or wells at a small, very sharp 12-in. radius of curvature from a central vertical well. With this new system, horizontal radials can be placed at any depth radiating from a 5.5-in. or larger diameter vertical casing. Several stacked layers of radials can be placed from the same vertical well.

Placement of horizontal radials into a contaminated aquifer from a conventional vertical well can provide marked enhancement of access to the formation. Because most aquifers are near horizontal, the placement of wells in the plane of the aquifer should increase the collection/injection area of a well, as compared to placement of vertical wells across the aquifer. With that intrinsic geometric advantage, the volume of formation that can be serviced by a well is markedly increased. Hence, fewer vertical wells need to be drilled, and a more uniform access to the contaminated aquifer is provided.

This paper first will describe the short radius horizontal radial

drilling system and associated well completion methods. Application of this horizontal technology to hazardous waste site problems then will be discussed.

HORIZONTAL RADIAL DRILLING SYSTEM

Over the past 6 years, Bechtel Group and Petrolphysics Ltd. have been developing a completely new technology of placing and completing horizontal drain holes or radials. That technology was developed primarily for enhanced recovery of both heavy and light oil in both shallow and deep oil reservoirs.

The Petrolphysics/Bechtel radial system consists of a pattern of radials radiating from a central vertical well. Several such patterns can be spaced vertically at different depths in a single well. These radials extend into the formation for distances up to several hundred feet (Fig. 1). To place the radials an erectable whipstock is lowered downhole into a previously underreamed cavity. The whipstock is loaded with a long 1.25-in. diameter steel continuous tube which has a hydraulic drill head welded to its nose. High pressure water drilling fluid is pumped through the steel tubing. The hydrodynamic forces on the drill head pull 1.25-in. tubing through the whipstock, making a 90° turn at a very short 12-in. radius. The tube then moves horizontally into the formation.

Several radials may be placed at a specific horizon to allow injection or drainage from contaminated hydrogeologic units. Each radial is completed in situ by electrolytic perforation of the tubing and by placement of a gravel pack within the radial well bore around the steel tube.

FIELD RESULTS AND COST OF RADIAL PLACEMENT

Over 27,000 ft of 1.25-in. diameter horizontal radials have been placed during development and commercial production operations. These radials have been placed at various depths from nearsurface down to 6,800 ft in several parts of the United States and in Canada. As shown in Fig. 2, multiple radials can be placed at the same depth, and patterns of radials can be placed at multiple levels from a single vertical well. As many as 100 radials have been placed in a single well at three different levels.

The drilling is done hydrodynamically, and the radial is pulled into the formation by its own hydrodynamic force (Rabbit Force) which always keeps it in tension. Hence, the radial naturally tends to go horizontal and straight. A wide variety of geologic formations from unconsolidated formations to beds of granite cobbles have been successfully penetrated.

In the oil industry, the total cost of radial placement in deep oil reservoirs is about \$135,000 for four 1.25-in. radials of 100- 10 200-ft length. This cost includes the deep drilling rig, tubing



strings, pumps and all services including logging. The incremental cost of placing more than four radials is small because the placement time per radial is very short. For shallow applications of radials such as Superfund sites, these radial placement costs should be reduced by 50% or more both because of a lesser equipment requirement and a substantially lesser time requirement.

DRILLING SYSTEM DESIGN

Drilling and Drill String Propulsion

Drilling of the formation and propulsion of the drill both use the same hydrodynamic force. This force concurrently pulls and pushes forward the radial tube or drill string. The force both digs the bore hole and pulls the string into that hole; hence, it is called the Rabbit Force.

In drilling, the drill string begins vertically, proceeds around a 90° whipstock turn and then enters and rapidly penetrates a formation horizontally. Typical velocities are 5 to 120 ft/min in unconsolidated formations. The same fluid pressure forces are further applied to control the vertical movement of the drill string while drilling. The overall drilling system configuration is shown in Fig. 1.

Pulling and Pushing Force

The 1.25-in. drill string is vertical and contained in a sealed chamber made up of a working string of larger diameter drill pipe from the surface down to the whipstock. The 1.25-in. drill string is placed within the larger working string and thence passes through a fixed high pressure chevron seal in the top of the whipstock.



FOUR RADIAL PLAN VIEW



TWELVE RADIAL PLAN VIEW

Figure 2 Well Radial Patterns

The high pressure drilling fluid, usually water at 8,000 to 10,000 lb/in.², creates a pulling force (Rabbit Force) on the nose of the string. This pulling force keeps the string in tension so that it tends to go straight. The same fluid pressure exerts a pushing force on the cross-section of the posterior of the drill string. This pushing force helps push it through the seal/whipstock system. For example, at 10,000 lb/in.² pressure in a 1-in. ID tube, the net pulling force is about 8,000 lb. A pushing force of about 3,500 lb is exerted on the posterior of a typical 1.25-in. tube. The combined result is a total push/pull forward force on a 1.25-in. tube of approximately 11,500 lb.

Whipstock

The next major component of the system is the whipstock shown in Fig. 3. The whipstock is lowered on the end of a larger diameter working string. It is then erected downhole in a previously underreamed zone. The whipstock contains a set of slides and wheels that enable the 1.25-in. steel drill string to move continuously and rapidly from the vertical, around the 90° whipstock turn, through the exit section or straightener and thence out horizontally into the formation.



Figure 3 Mark I Whipstock



ELECTRICAL SCHEMATIC



Figure 4 Model V, Radius of Curvature Tool



Figure 5 Spinning Jet in Unconsolidated Formation



Radial Well Completion with Perforations

Because the drill string is triaxally stressed during this process (hoop stress plus axial stress plus bending stress), the deformation of the 1.25-in. string at a 12-in. radius can be accomplished at low incremental stress. In effect, the 1.25-in. tube is in a transient plastic state. Many radials can be placed with the same whipstock at the same level and at several different azimuths without tripping that whipstock uphole. If desired, the whipstock can be used to place stacked layers of radials in the same vertical well.

Radial Restraint and Control System

Some real-time control of radial pitch or inclination can be achieved by controlling the drill string velocity as it moves through the formation. To provide that control of velocity, especially during progress through the whipstock and during initial entry into the formation, a cable restraint is applied. As shown in Fig. 1, this consists of a cable restraint truck and a wellhead high pressure grease seal at the surface. A connecting cable runs down to a removable disconnect at a tail of the 1.25-in. drill string. This disconnect is removed after a run to permit the entry of wire line logging tools. The restraining cable instrumentation gives a realtime indication of both the extent and rate of drill string movement.

An alternate restraint system to keep the radial from moving too fast uses a hydraulic tail which is constructed much like a double acting shock absorber so that the radial is restrained and its velocity is controlled by a closed fluid system. This eliminates any cable connection to the 1.25-in. radial.

Electrical Downhole Logging

Following the placement of a radial, it is usually desirable to precisely locate the radial bore hole in three dimensional space. A



Figure 7A Conventional Vertical Well Field



Figure 7B Well Field with Vertical Well and Horizontal Radials



' Figure 8 Leachate Monitoring or Collection by Horizontal Radials



Vertical Well System in Fractured Media



Figure 9

highly flexible directional wireline logging system, the Model V Radius of Curvature Tool, has been developed and commercialized for this purpose.

The Model V Tool, shown in Fig. 4, can be pumped down the 90° whipstock turn within a 1-in. ID tube to yield three dimensional data on the radial trajectory. The tool yields vertical and horizontal location; the length of the wire line cable yields the length of trajectory.

Model V is built around a flexible backbone with small movable slide wires placed at 90° to each other. Differential movements of these slide wires on the inner and outer radius when the tool is bent within the 1.25-in. drill string result in electrical signals that provide a reproducible indication of curvature of the drill string down which the tool has been pumped. The tool also can function under several thousand psi hydrostatic pressure.

Model V can locate and print out the location of the 1.25-in. radial with reproducible accuracy of better than 99%. This tool is commercially operational.

Spinning Jet Drill Heads

A major improvement in fluid jet drill heads, the Spinning Jet, has been developed (Fig. 5). These drill heads in general produce a thin, conical shell of water which, in turn, is believed to create a toroidal slurry body of cuttings; this toroidal body would be shaped like an inflated inner tube. These cuttings appear to act as a rotating body of abrasive slurry because this drill head cuts both hard crystalline rocks and consolidated sedimentary formations. In effect, the cuttings are the cutter. The technology also is applicable to other down hole processes such as underreaming. With the Spinning Jet drill head, it is possible to cut unconsolidated formation at 5 to 120 ft/min. The resulting bore hole diameter may be selected and varied from 4 to 24 in. by controlling the internal angle of the conical shell of water particles.

For harder materials analogous to Berea sandstones, the penetration rate for a 4- to 6-in. bore hole is several in./min. For hard granite rocks, the penetration rate is one or more in./min. The Spinning Jet drill head applied to an unconsolidated formation is shown in Fig. 5.

RADIAL WELL COMPLETION METHODS

Once the radial tubing is in place in the formation and its location is logged, the well can be completed by perforating the radial, gravel packing and placing the flexible slotted liner. These methods have been demonstrated in the laboratory on 80-ft full-scale radials.

Gravel packing of the annular space between the radial bore and the steel radial tube is conducted with a two-step, bi-directional process which provides a 100% fill of consolidated gravel. The gravel is placed in a slurry using water as a transport medium.

To allow fluid infiltration from the formation into the radial, the 1.25-in. radial tube can be perforated in situ by an electrolytic perforator tool. Over 120 perforations can be made simultaneously. The perforations are round, sharp-edged orifices, and perforation size can be controlled from the surface while the perforating process is underway.

A flexible slotted liner then can be placed within the perforated radial to keep gravel or formation sand from entering the well perforations. Flexible liner permeability can be selected over a wide range to preclude any formation fines from being carried into the radial by the fluids.

Wire brush filters then are placed at the ends of the radial to prevent gravel pack gravel from entering into the slotted radial. The total radial well completion system is shown in Fig. 6.

The final well construction therefore consists of an array of horizontal wells which can extend laterally up to 200 ft from the central vertical well. The location of each horizontal well bore is defined from the electronic downhole logging. The radial bores are gravel packed, and the steel radial tube is perforated and lined to prevent migration of the gravel pack or formation fines into the 1.25-in. radial tube. These radial tubes are terminated in the underreamed zone of the vertical well. A standard submersible pump and a vertical slotted liner then can be placed in that central vertical well.

APPLICATION OF HORIZONTAL WELLS TO WASTE PROBLEMS

There are several potential applications of horizontal well methods to hazardous waste problems. The most obvious potential applications include groundwater control and in situ modification. The benefits of horizontal drilling arise primarily from the ability to intercept horizontal groundwater and geologic structures. Thus contaminant plumes may be penetrated laterally rather than vertically.

Groundwater Control

The typical well field treatment scheme consists of several vertical wells laid out in an array which intercepts and withdraws the contaminated plume for treatment (Fig. 7A). The design of the well field is dependent on site specific parameters such as aquifer transmissivity, plume geometry, groundwater characteristics, contaminant characteristics and surface restrictions. Surface restrictions include power or process plants, office and industrial buildings, suburban developments, streets, highways and powerline corridors. Natural surface restrictions, such as water bodies, also may restrict well field construction.

Vertical wells draw water in all directions within the cone of depression as shown in Fig. 7A. Large amounts of water are drawn in from the plume area as well as some clean groundwater. The mixed groundwater is collected by a header system for treatment. Thus potentially large volumes of water for treatment may be generated.

A horizontal radial well system shown in Fig. 7B could help to overcome the typical problems shown in Fig. 7A. As shown in Fig. 7B, a limited number of central vertical wells can be strategically placed to deploy horizontal radial wells within the contaminant plume area. The radials can be placed beneath existing surface facilities without disruption. The horizontal radial well system thus reduces the number of vertical wells, the footage of drilling and the number of screens and pumps.

Aquifers with low transmissivity require a larger number of conventional wells since they need to be placed on closer spacing. Hence well field operating costs are high in contaminated aquifers of low transmissivity due to the long operational period for extraction and treatment. The alternative of using horizontal collector radials could provide significant cost savings by requiring fewer wells and providing lower operating costs.

Subsurface Drains-Leachate Interception

The horizontal radial system allows the placement of radials directly beneath existing surface and shallow burial waste facilities (Fig. 8). The horizontal radials allow the interception of leachate from disposal trenches prior to migration and mixing with groundwater.

Placing perforated horizontal radials in the unsaturated zone beneath the disposal trench or tank also could allow the deployment of leachate detection equipment such as vapor monitors. Leachate detection monitors could possibly be designed to function on a perforation by perforation basis within the radial to give contaminant concentration gradient data along the radial.

In disposal areas where the migration of leachate is primarily via vertical fracture flow, a perimeter horizontal radial array would intercept vertical and steeply inclined fractures. The perimeter array allows detection and monitoring in the unsaturated vadose zone. In the saturated section, monitoring is supplemented by the ability to pump and treat leachate prior to migration offsite. A horizontal monitoring array thus has obvious significant advantages over the conventional vertical monitoring well system, since effective monitoring is dependent on interception of vertical fractures (Fig. 8). Horizontal radials will intercept such fractures much more effectively than vertical wells. The effectiveness of intercepting vertical fractures with horizontal radials for improved oil production already has been successfully demonstrated commercially.

Injection Wells

Similar advantages exist when using horizontal radials to inject groundwater to change flow and gradient or to discharge treated groundwater. The injection can occur along a horizontal line across the aquifer, which significantly reduces the number of vertical wells typically required.

In Situ Modification

The horizontal drilling system has the unique ability to penetrate contaminated soil and groundwater plumes in a horizontal plane regardless of the depth below ground surface. The horizontal radial can be utilized for a wide variety of in situ treatment methods: (1) injection of acids for neutralization, absorbing clays or reactive chemicals, (2) injection of micro-organisms and nutrients and (3) physical modification by freezing or grouting. The latter two methods are of particular interest. Bioremediation is a developing method for in situ treatment of certain petroleum products and volatile organic compounds. These contaminants often occur as horizontal lenses within the soil or floating along the water table surface. The introduction of microorganisms and nutrients along a horizontal line or radial array within the contaminant lense would allow rapid in situ degradation.

In situ modification by solidification/stabilization can be effected by binding waste within a solid mass. Solidification can be accomplished through grout injection (cement or polymer) and through freezing by continuous circulation of a refrigerant or injection of a cryogenic liquid. Conventional grout injection consists of an array of numerous vertical holes through which cement or a chemical grout is injected under pressure. The grout permeates the pores and the fractures in the formation prior to solidification at its set time. In situ freezing is accomplished through injection of cryogenic fluids (nitrogen, liquid nitrogen or liquid carbon dioxide) through a well and header of concentric pipe system. Horizontal wells placed in a contaminated aquifer or orthogonal to vertical fracture sets would allow a more effective means of in situ solidification.

As shown in Fig. 7B, in some emergency applications radials could be placed remotely and rapidly as after a catastrophic accident at a nuclear or chemical plant. Such a procedure possibly could have been applied to a situation such as Chernobyl in the USSR to provide grouting beneath the failed reactor without requiring personnel to be near or under the reactor.

CONCLUSIONS

The application of horizontal radial well methods to waste

problems offers another subsurface dimension to contaminant collection, monitoring, treatment or immobilization both in unsaturated and saturated materials. Such radials can be placed around the periphery or beneath a waste disposal site where they can monitor leakage or collect leaked fluids.

For permanent immobilization, radials offer the opportunity to grout along horizontal injection holes. For temporary stabilization, injection of cryogenic fluids along radials could effectively freeze a plume in place. In emergency situations, radials could be placed very rapidly beneath a failed and leaking plant to provide grouting to isolate potential leakage into the groundwater.

Many radials can be placed from a single vertical well. These radials can be placed in one horizontal plane or in several layers stacked above each other. The total radial placement operation is done very rapidly.

ACKNOWLEDGEMENTS

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Performance Evaluation of Cement-Bentonite Slurry Wall Mix Design

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ABSTRACT

A cement-bentonite slurry cut-off wall is a variation of the slurry wall process that is used to create an underground barrier to stop the lateral flow of groundwater and other fluids. Because of the relative simplicity of the construction process, the cement-bentonite technique might be chosen over other types of slurry cut-off walls in situations with poor across or poor subsoil conditions. The characteristics and engineering properties of cement bentonite are generally not well understood and are poorly documented. This paper documents a case study where enough testing was done to draw significant conclusions.

The principal findings of this study were the moderate increase in strength and decrease in permeability which result when fly ash is added to cement-bentonite. In addition, sampling and testing techniques were found to have little effect on the cement-bentonite permeability. Due to the complexity of the cement-bentonite sealing mechanism, only long term permeability tests were appropriate to evaluate cement-bentonite permeability.

INTRODUCTION

Slurry cut-off walls have been used in the United States for about 40 years to control the lateral migration of groundwater and other fluids. The slurry wall system uses bentonite slurry (similar to drilling mud) to facilitate the excavation of a vertical-walled slot or trench into the ground. This slot subsequently is backfilled with various materials, depending on the application.

The most popular type of cut-off wall is the soil-bentonite (SB) variety where the trench is backfilled with a blended mass of soil and bentonite. At least 90% of the installations of slurry cut-off walls in the USA are SB walls.

The cement-bentonite (CB) wall is a variation of the process in which cement is added to the slurry so that, after the excavation process, the slurry sets up without a separate backfilling operation. This paper concentrates on the CB technique and particularly on the permeability of various mix designs and the procedures for testing the mixes.

CEMENT-BENTONITE TECHNIQUE

The CB slurry typically is prepared in a remote plant (Figure 1); bentonite and water are blended together and the cement is added just prior to pumping the material to the trench. Trenching is done with a backhoe (Figure 2) or other suitable equipment. After a period of about 12 hr, the CB slurry sets (Figure 3). The result is a non-structural cut-off wall that, even when it is fully met, acts like a stiff clay and can be dug with a hand shovel.

The CB technique has some advantages that make it the technique of choice on certain sites:

- The back fill mix is a controlled material whose properties may be more homogeneous and more consistent than soil-bentonite.
- The technique is not dependent on the quality of soil excavated from the trench, since it is not reused. This is helpful on sites

where the soil profile contains rubble, refuse or other unusable material.

- Since there is no separate backfilling operation, it is much easier to install CB throughout areas of tight access such as the tops of dikes, between buildings, etc.
- The panels may be joined together with previous work by simply re-excavating the end of the set-up panel. This enables a simple construction procedure on sites where, due to maintenance of traffic or other considerations, the trench must be installed in discontinuous sections.



Figure 1 CB Slurry Mixing Plant



Figure 2 Trenching Under CB Slurry

There are several disadvantages to the CB technique, however, that have led to its limited use when compared to the SB technique:

- Due to the addition of cement to the backfill blend, the cost of CB will be more than a comparable SB project unless one of the technical advantages listed above presents a significant economic benefit.
- CB mixes, in most cases, yield permeabilities in the range of 10⁻⁶ cm/sec, whereas SB usually can be mixed to provide nermeabilities in the range of 10⁻⁷ 10⁻⁸ cm/sec.
- Because of the high water content of the set mix and the relative susceptibility of both cement and bentonite to various types of degradation by waterborne contaminates, CB walls are not always the best choice for sites that have contaminated groundwater. Leachate compatibility tests may be run to confirm this on a case by case basis.

APPLICATIONS

The CB technique was developed in Europe in the late 1960s and continues to be used there almost exclusively instead of soilbentonite. The first application in the United States was in 1973 for a cut-off under a dam in the southeast. Since that time, there have been many projects, some quite large. Perhaps the most dramatic was the work done at Braidwood Nuclear Power Station in the mid 1970s. The plant site was dewatered by 1-mile long, 30-ft deep CB wall. Subsequently, the cooling lake for the plant was isolated by miles of slurry wall up to 120 ft deep.

Since the early projects, a better understanding of CB properties and advantages has begun to evolve; now most applications are more appropriately engineered. There had been, for example, the notion that CB is "stronger" and more resistant to loads than SB. In fact, the opposite can be true. CB generally is stronger in unconfined compression tests, but SB usually is stronger and less compressive when consolidated and tested under triaxial conditions. The result of the new understanding of CB has been a more appropriate use of the product.

Currently, the most typical applications are those where difficult access is involved (Figure 4) and the CB represents an economic invantage over SB by eliminating the backfill mixing operation. Examples are (1) situations where the cut-off wall passes through plant sites with buildings close by and (2) along the narrow tops of containment dikes. There have not been many environmental applications for the reasons stated earlier. The major exception is tank farm containments for underground spills of petroleum products (Figure 5). Oil and gas usually have no deleterious effect on the CB material, and the tough access conditions around most tank farms make the CB method economically attractive. Sometimes it is possible to key the wall into the lowest seasonal water table and literally skim the floating product off the groundwater surface.



Figure 3 Set-up CCB Slurry



Figure 4 CB Work in Area of Tight Access



Figure 5 Schematic of Typical Application Oil-Polluted Groundwater

It is worth noting that the first Superfund project ever carried out (Stroudsburg, Pennsylvania) used a CB wall for containment. In retrospect, this application may have been somewhat inappropriate; all subsequent superfund slurry wall containments have used the SB technique.

MIXED DESIGN CONSIDERATIONS

The determination of appropriate ingredients for cementbentonite requires a knowledge of the material properties and their interactions and an understanding of mixing technology. An appreciation of slurry workability, recognition of project specifics and experience must be added to this list. Most knowledge about CB comes from previous experience, much of it with proprietary mixtures and mixing techniques.

The basic component of cement-bentonite slurry is the bentonitewater mixture. Specifically engineered cement-bentonites generally are created by changing the cement content or by adding other ingredients to the bentonite-water slurry. The final properties of cement-bentonite are a function of the initial mix proportions, curing time, soil conditions and sampling and testing methods. Some commonly specified mix proportions are given in Table 1. More exotic mixtures may contain fly ash and set retarders. In general, cement-bentonite mixtures for slurry trenching are specified by performance criteria.

The performance limits of cement-bentonite are defined by the following major restraints:

- The slurry must be pumpable and allow excavating equipment to penetrate it easily for extended periods. High cement and/or bentonite proportions and fly ash can increase slurry viscosity; set retarders can decrease viscosity.
- The slurry must set within a definable period. Too little cement or too much fly ash can impede the set. Set retarders may extend the fluid state, although unpredictably.
- The slurry properties must be controllable and regular within limits. Fly ash is generally of irregular quality and may adversely affect slurry viscosity without the use of set retarders.
- A continuous, low permeability barrier must result. Too little bentonite can result in higher than expected permeabilities. A higher solids content generally leads to lower permeabilities.
- The set slurry should be strong enough to resist hydraulic and earth pressures, yet flexible enough to resist cracking and earth movements. Too much cement or fly ash can result in a material which is stronger, yet subject to brittle failure at low strains. The mixture of materials used in cement-bentonite slurries is

known to meet the above criteria depending upon mix proportions. Any significant change in the proportion of one ingredient can affect the entire mixture in ways which may make the product unusable either in the liquid or solid state.

SAMPLING AND TESTING TECHNIQUES

During a recent project in southern California, three separate design mixtures were used to construct five cement-bentonite groundwater barriers. Four well-known independent testing laboratories were employed to perform various tests on the fieldmixed cement bentonite. Samples of the cement-bentonite were obtained from the trench while still fluid. Other samples were cored from the set-up wall using thin tube samplers months after construction. Over 100 permeability measurements were made and 15 unconfined compression tests were performed.



Figure 6 Influence of Curing and Testing Conditions On the Permeability of Cement-Bentonite Samples

Fluid samples of cement-bentonite slurry were gathered from the mid-depth of the trench when each panel was completed. The still-fluid samples were poured into 3-in. diameter plastic tubes of two lengths, 1 ft and 3 ft. The samples were capped, sealed and allowed to set undisturbed on-site for 3 days in a climate-controlled construction trailer.

Due to the long time lapse between construction and final cure, it may be desirable to somehow artificially accelerate the cure of the slurry in order to monitor performance of the installation. Some of the 1-ft samples were artificially cured in a water bath (at 140°F) for 5 days. The samples were extruded, trimmed to a workable length and tested in a triaxial permeability apparatus for 3 days including time for consolidation. The 3-ft samples were allowed to cure at room temperature for at least 28 days and were tested in a triaxial permeability apparatus for a period of 7 to 8 weeks.

A comparison of the results is presented in Figure 6. The quick cure method did not produce an acceptable agreement with the naturally cured samples. The average ratio of permeability of the artificially cured samples to the naturally cured samples is about 5. This discrepancy could be due to other factors beyond cure conditions. In order to ascertain the source of this discrepancy, a comparison was made to evaluate the effect of the sampling and testing techniques on permeability.

The results of the comparison between the different sampling techniques are shown in Figure 7. No obvious or persistent differences are evident; however, there is a slight tendency for the undisturbed samples to give slightly lower permeabilities. In situ cure conditions, consolidation stresses and water loss through the trench walls may have contributed to this trend.



Permeability Results from Various Sampling Techniques (All Samples Cured at Least 30 Days)

A separate comparison was made to evaluate various testing parameters on cement-bentonite permeability. The factors evaluated were sample size, permeant, test method and consolidation stress. The results are presented in Figure 8. Again, testing effects are rather insignificant, with increased consolidation pressures giving the most noticeable effect.

DESIGN MIX PERFORMANCE

Unconfined compressive strength tests were performed to evaluate the strength of the three cement-bentonite mixtures. The results of these tests are presented in Figure 9 along with design curves from previous work by others. In all cases, the strengths were somewhat higher than expected. We assume that this was due to higher than normal water loss from the slurry into the trench walls. The slurry walls were constructed in essentially dry ground, well above any permanent groundwater level. The dry ground permitted some of the free liquid to pass out of the slurry with a resulting increase in solids accumulated in the trench and, thus,



Figure 8 Permeability Results Using Various Testing Techniques (All Values of Hydraulic Conductivity Obtained After 3-5 Days of Flow)



 After Millet, Richard A., and Perez, J.Y., "Current USA Practices: Slurry Wall Specifications," Journal of Geotechnical Engineering Division, ASCE, Vol. 107, No. GTB, August 1981.

Figure 9 Influence of Cement and Fly Ash Proportion on Compressive Strength of Cement—Bentonite After Various Curing Periods

higher strengths. We observed that some of the samples at the highest fly ash content cracked when extruded after being subjected to the accelerated cure.

The results of permeability tests on the three design mixes are given in Figure 10. All results are for short term permeabilities (3 to 7 days of flow) with tap water. The most apparent trend is the rather large and overlapping range in permeabilities for all three mixtures. For instance, although the lowest average permeability was produced by Mix 3, the lowest absolute permeability was obtained from Mix 1. In an average sense, the CB with fly ash did result in somewhat lower permeabilities.





Figure 10 Permeabilities of Various Cement-Bentonite Mixtures

LONG-TERM TESTS

Longer-term permeability tests were performed on samples of the cured cement-bentonite with and without fly ash. Results are presented in Figure 11. The most obvious similarity in the mixes is that they apparently achieve their low permeability after some time and with continued flow. It appears that the mechanism controlling permeability may be pore plugging and/or consolidation. Particle migration frequently was observed in the laboratory by the presence of minute particles which flowed out of the sample during testing. Although repeated efforts were made to clear the test apparatus of these particles, it was apparent that particle migration within the sample during permeation contributed to an eventual lowering of the samples' permeability.



Figure 11 Results of Long Term Permeability Tests on Undisturbed Samples of Cement-Bentonite (Mix No./Permeant)

The effect of this phenomenon in the field is unknown. One would surmise that as long as free water is available, cementing and bonding continues within the barrier leading to an eventual decrease in available flow channels and an accompanying drop in permeability.

	Table 1	
Common	Cement-Bentonite	Specifications

Cement/Water (%)	16-35
Bentonite/Water (%)	3-6
Viscosity (Marsh Funnel Seconds)	35-90
Unit Weight (gm/cc)	≥1.15
Unconfined Compressive Strength (psi)	≥5
Strain at Failure (%)	≥15
Hydraulic Conductivity (cm/sec)	$\leq 5x10^{-6}$
Curing Time (days)	≥28

CONCLUSIONS

A large number of tests on field samples of cement-bentonite slurry walls resulted in the following conclusions:

- Artificially accelerating the cure of cement-bentonite leads to conservative permeability test results.
- Cement-bentonite is relatively insensitive to laboratory test conditions. Effective confining stress is the most important variable investigated.
- The addition of fly ash to cement-bentonite was shown to moderately increase strength and reduce average permeabilities.
- Pore plugging by particle migration may be an important mechanism of cement-bentonite impermeability and was observed during long-term permeability tests.

Additional research and more documented case studies are needed to help the engineering community fully understand cementbentonite mixes.

Geomembrane Uses with Hazardous Wastes

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ABSTRACT

This paper discusses the use of geomembranes with hazardous wastes. It concentrates mainly on polyethylene geomembrane which is the predominant material being used because of its superior strength and chemical resistance properties. This paper includes sections on manufacturing, quality control, failure modes, seaming methods and monitoring.

INTRODUCTION

The first synthetic materials began to appear as liners for use in water retention ponds and canals in the 1940s. In the early days, butyl rubber was the most commonly used material. As the development of polymers and the need for synthetic liners increased, more base materials were commonly used for liners. Today, the most common base materials used as liners are:

- Butyl Rubber
- Chlorinated Polyethylene
- Chlorosulfonated Polyethylene
- Ethylene Propylene Diene Monomer
- Polyethylene
- Polyvinyl Chloride

In the beginning, liners were referred to as Flexible Membrane Liners. Later, because liners did not show immediate permeation to liquid, they were called Impermeable Barriers. Today, synthetics are being referred to as Geomembranes. Applications have expanded from canals and water retention ponds to many other uses. Included among these uses are curtain walls, floating covers, landfill caps, renovations, tunnels and underground storage.

Recently, geomembranes have become more popular because of new regulations where they can be one of the least costly alternatives for hazardous waste containment. Because hazardous wastes, in most cases, contain organics (particularly aromatics) the predominant material being considered for containment is polyethylene due to its overall superior chemical resistance. Another problem with many hazardous waste containment applications is that the exact compositions and concentrations of the wastes are unknown. Another reason polyethylene is the predominant geomembrane in hazardous waste containment is that many of these applications contain solids, etc., and polyethylene's superior strength properties become advantageous.

POLYETHYLENE

Polyethylenes generally are classified into one of three categories described below.

Low Density Polyethylene (LDPE)

LDPE is produced by high pressure polymerization yeilding a

non-linear chain. LDPE is not commonly used as a geomembrane since the other polyethylene materials have improved strength and chemical resistance properties.

High Density Polyethylene (HDPE)

HDPE is produced with low pressure polymerization yielding a linear chain. Materials produced by this process generally are used as liners only when the material density is below 0.942, as higher densities would be too stiff and would not pass the stress crack test. HDPE geomembrane materials are, in fact, HDPE copolymers where the copolymers are 1-hexane or 1-butene which is used to obtain side branching and reduce density.

Linear Low Density Polyethylene (LLDPE)

LLDPE is produced with low pressure polymerization yielding a linear chain but lower density. LLDPE is the newest member of the polyethylene family. With its lower crystalline nature, LLDPE gives the polymer added flexibility with a molecular weight for chemical resistance. There are LLDPE materials that demonstrate superior ultimate tensile, tear and puncture resistance over the common HDPE liners.

MANUFACTURING

Polyethylene geomembranes typically are manufactured by two processes.

Sheet Extrusion

In the sheet extrusion process, the molten plastic is forced through a die under pressure to form the final sheet thickness required. This process lends itself to sheet thicknesses in excess of 20 mils. Sheet widths of up to 12 ft are produced in standard sheet lines, and specialized processes have been developed to produce greater widths.

Blown Film Extrusion

In the blown film extrusion process, molten plastic is extruded through a tubular die in a vertical direction. Air is blown through the die to form a bubble. The bubble is cooled, collapsed/flattened at the top of its travel and then passed through a wind-up system. This process lends itself to making extremely thin gauges (even below 1 mil) to thicknesses over 100 mils. Common widths exceed 20 ft.

MANUFACTURING QUALITY

It is important to ensure the use of good quality control procedures in manufacturing. Because polymer manufacturing is a controlled process in an enclosed environment, there are minimal problems arising from the original producer. However, it is imperative to keep good records. These records should include all materials, operating conditions and samples of not only the finished product but also all basic raw materials. The most important recorded physical properties of a polyethylene sheet are:

- Thickness
- Continuity
- Tensile Properties
- Tear
- Puncture
- Stress Crack Resistance
- Density
- Percent Carbon Black
- Melt Index

FAILURE MODES

An application engineer should understand the potential causes of failure in the initial selection process. Polyethylene, like all synthetic materials, has its limitations. The more information one has about the intended application of the material and the ability to relate this future use to the geomembrane, the more one can reduce the chance for failure. The most common sources of failure are described briefly below.

Weatherability

Weatherability studies should include verification of the temperature extremes as well as the ultraviolet resistance of the polyethylene. Generally, polyethylenes have a constant use temperature range from -70 °C. to +90 °C. At high temperatures this could be affected by chemicals; whenever liquid temperatures above 70 °C. are expected, verification tests should be run. Polyethylene is well known for its ability to withstand sunlight if properly compounded with carbon black. The ability to withstand UV relates to concentration, type and dispersion of carbon black in the polymer. Generally, the specification should include a 2.0% minimum carbon black of an ASTM N550 grade or better and a dispersion rating by ASTM D3015 of A1.

Chemical Resistance

The primary purpose of a liner is to protect the groundwater from contamination. Thus the liner must be resistant to the chemicals it is expected to contain. It is advisable to test the material against the worst case temperature and contaminant concentration expected. Unfortunately, there are many areas which make chemical compatibility projections difficult. Among these are:

- Concentration
- Future Chemicals
- Temperature
- Internal Reactions

Tear and Puncture

One source of potential geomembrane failure is tear and puncture. Polyethylene's tear and puncture properties are linear to thickness. However, recent data show that the use of geotextiles can greatly enhance the puncture resistance of a polyethylene geomembrane. Typical results show that a 40 mil liner in conjunction with a 6 oz geotextile can give puncture values greater than 100 mil polyethylene alone. Not only does a cost savings occur, but also one can expect other benefits, such as constant welding surface, subsoil stability, potential help in leak detention, reduces abrasion and improved venting.

Seam Failure

Probably the most common cause of geomembrane failure is seam failure. This failure usually is caused by poor workmanship in the field seaming.

SEAMING METHODS

Polyethylene seaming is unique because the bond can be

stronger than the parent material. Polyethylene seaming methods do not include the addition of materials other than polyethylene, and thus there are no seam failures caused by adhesives not being resistant to the chemicals.

There are several polyethylene seaming methods, but all basically rely upon heating the two sheets to be bonded so that the resultant seam is as one. All seaming methods require applied pressure following the heating, and all rely upon time, temperature and pressure. Hot air simply melts the two surfaces to be bonded. Fusion uses molten plastic to effect the bond. Extrusion welding adds new material via the extrusion process either between two sheets or as a filet type weld. Finally, "hot shoe of hot wedge" welding melts the surfaces to be bonded by use of a hot metal shoe or wedge.

All of these systems will give an excellent weld that is stronger than the parent sheet if done properly; conversely, all will give poor welds if not done properly. In the field, extra care is needed to ensure the best results. Sometimes unpredictable factors must be accounted for (i.e., temperature changes, wind velocities and contamination). In all methods, simple precautions such as precleaning the surface prior to seaming are common sense but quite often are overlooked.

INSTALLATION

The installation of a polyethylene geomembrane not only is the most critical step, but also is the most difficult step to manage and control. Because the liner is subject to uncontrollable factors such as potential wind damage, traffic on the liner, etc., it is advisable to continually inspect the liner during installation in addition to the final inspection upon completion. Because seams are most prone to future problems, they should be given the closest scrutiny.

INSTALLATION QUALITY

Upon arrival, the geomembrane should be inspected to ensure no damage occurred in transit. Samples should be taken for verification of physical properties as well as thickness, etc. Before installation commences, engineering and site specifications should be checked for conformance. The placing of the liner should be controlled to eliminate or minimize damage to the material. Once seaming starts, it is important to do the testing and quality control along with the actual installation. This testing begins with non-destructive tests. The four most common tests used with polyethylene seams are:

- Air Jet Testing
- Impact Testing
- Ultrasonic Testing
- Vacuum Box Testing

The above non-destructive tests, in essence, only tell one whether one has a leak or not; they do not test the integrity of the seam. Even though these tests will show a seam that needs immediate repair, they cannot be relied upon for complete quality analysis. Thus, it becomes essential to do destructive tests. There are two destructive tests used with polyethylene:

- Tensile Testing
- Peel Testing

The peel test is considered the best method for assessing bond strength. In this test, a force is applied against the bond in a severe manner. A good bond will exhibit ductility and elongation, whereas a poor bond will crack or peel apart easily under low force. If the bond is stronger than the liner, the liner will tear away from the bond before the bond peels or breaks. This is referred to as film tear bond or "FTB." It is advisable to keep samples of seams for future reference and testing, if needed. During the seaming process, all conditions for seaming should be checked before starting. Samples should be produced under exact site conditions. All conditions for seaming should be rechecked, and good seams should be verified if the following excessive delays or major changes in the environment occur:

- A temperature change of more than 10 °C
- A change in wind velocity of more than 15 miles/hr
- A change from dry to wet, etc.
- A change in the seaming surface
- A change in barometric pressure

MONITORING

In addition to the normal leak detection systems, it can be advantageous to make efforts to monitor the system to discover potential problems before a leak occurs. A few recommendations would be:

- Place coupons in the contained medium so that testing will show if any side effects are taking place because of chemical ' attack, exothermic reactions, etc.
- Place coupons above the containment line to measure any adverse effects caused by ultraviolet light or weathering.
- Keep environmental records including wind velocities and temperature extremes.

CONCLUSIONS

As long as geomembranes are used in the containment of haz-

ardous wastes, it is important to make the best evaluation possible in the selection process to reduce the chance for failure. This paper deals mainly with polyethylene geomembranes, but the points made would still have some validity with other synthetic materials. Because of the dangers that can be associated with a failure, it is important that everyone involved in the process of liner production/installation cooperate in a joint effort from inception to completion. It is hoped that this paper contributes to this effort, if only in a small way.

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Nondestructive Testing Techniques to Assess Geomembrane Seam Quality

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ABSTRACT

A review of the various nondestructive testing (NDT) techniques for geolmembrane seam integrity is given. A bonafide NDT technique is desperately needed which will test 100% of all field seams. At present, such a technique does not exist. In the authors' opinion, ultrasonic techniques are the only ones which will perform the task. Some experimental results are presented for the pulse-echo and shadow ultrasonic methods on high density polyethylene seams. The ultrasonic techniques should be developed to their full potential in order to assure that field seams in geomembrane-lined landfills are as defect-free as possible.

INTRODUCTION

Liners and covers for hazardous waste landfills, surface impoundments and waste piles currently must use geomembranes for the prevention of unwanted liquids leaving or entering the contained waste. Almost every recent document regarding hazardous waste landfills, surface impoundments and waste piles has noted the need for 100% nondestructive testing of geomembrane field seams.' Current emphasis on construction quality assurance (CQA) makes this need an absolute necessity. Not only are seams along the sides and ends of full liner sheets important, but also the liner connection details around connections and appurtenances are absolutely critical. These connections are very often the cause of problems in lined waste facilities. Almost every study recently conducted lists inspection of field seams as a major deficiency. Additionally, these reports^{2, 3, 4} target a nondestructive testing method assessing 100% of the field seams as the highest priority. In the absence of high quality seams and their inspection, the "de-minimum" limits for leachate entering into leak detection systems of doubly lined facilities are ludicrous. One small length of bad seam can easily generate the complete amount of "de-minimus" leakage under almost any scenario. In the authors' opinion, field seams of FML are the Achilles' heel of liner design, construction and proper long-term functioning of waste management facilities.

Results of chemical compatibility exposure (via U.S. EPA 9090 test procedures) generally leave the liner material of choice as polyethylene. Furthermore, of the various available varieties of polyethylene, high density polyethylene (HDPE) is usually the liner material selected. While excellent for chemical compatibility, the constructability of HDPE is very difficult due to the following features:

- HDPE is a relatively hard polymeric liner material (its Shore Hardness is approximately 65 versus 20 to 30 for PVC)
- Due to this hardness and lack of flexibility, its conformability to the subsoil after placement is very poor
- HDPE has a low coefficient of friction (12° to 20° on various

soils)

- HDPE yields at a very low elongation (10% to 20% typically)
- There is controversy about the proper field seaming method (extrusion welding or thermal fusion) of HDEP with respect to the sheet thickness and its crystallinity
- The temperature window for seaming HDPE is very narrow (typically 100 °F, dependent upon the degree of crystallinity)
- Overheating and/or burn through of thin sheets of HDPE while making seams is not uncommon when using extrusion welding
- Thermal fusion of thin sheets is then necessary for field seams but generally is not used on thicker sheets
- Seaming around connections and appurtenances is very difficult irrespective of the seaming method.
- Superimposed upon the above listed difficulties of working with HDPE, and more specifically its field seams, is the absolute necessity of a rigorous CQA program

PROGRAM

Currently, the generally acknowledged need for quality seams usually is satisfied with the compliment of periodic destructive shear and peel tests (Fig. 1) to assess the specific seaming method and procedure and with nondestructive methods like the air lance or pick test (mechanical point stress) to assess seam continuity. Sometimes vacuum box methods also are used but only on a sporadic basis. While a limited number of destructive tests probably always will be necessary, the other tests mentioned fall far short of a ''true'' nondestructive test method. Needed is a nondestructive test where operator experience, sensitivity and judgment are kept to a minimum. Certainly this is not the case for the air lance or pick test which can be done in an almost cavalier manner. The vacuum box method is indeed worthwhile, but it does not lend itself to 100% continuous testing or to use around connections and appurtenances.

To give an overview of the entire seam monitoring spectrum, Table 1, after Frobel,' is presented. Since concentration in this article will be focused on HPDE, the NDT methods that one can consider are:

- Air lance (not recommended for geomembrane thickness 45 mils)
- Vacuum chamber
- Pressurized dual seam (for thermally fused seams only)
- Electrical sparking
- Mechanical point stress (pick test)
- Ultrasonic pulse echo
- Ultrasonic shadow
- Ultrasonic impedance

These test methods will be discussed in the next section.



Figure 1 Tensile Test Results of 60 mil HDPE Bulk Samples Compared to Welded Seam Samples. Seams on the Same Material Tested in Shear and Peel

DESTRUCTIVE AND NONDESTRUCTIVE TEST METHODS

The need for destructive tests, whereby a test specimen is actually cut from the seamed geomembrane and tested in tension until failure occurs, probably always will be a necessity. Results as shown in Fig. 1 for the unseamed material versus the seam tested in shear and peel are typical.⁶ It is reassuring to ascertain that the field-produced seam has the same values of mechanical properties (strength, elongation, modulus, etc.) as does the parent material. If these properties fall below accepted limits, then the necessary adjustments must be made in the seaming procedures.

Such items are critically important to the designer, manufacturer, contractor and ultimately to the facility owner. They are necessary items to qualitatively assess geomembrane seams. Their problem, however, is that they must be taken sparingly since each sample requires a patch (hence additional seaming) to be made at that particular location. Typical guidelines for taking of field seam test specimens are at the beginning of the morning and afternoon work periods and at intervals of one per 500 to 1000 ft. It is quite apparent that the areas between these test specimens must also be adequate but cannot be tested in a destructive manner. This is precisely what creates the need for nondestructive tests. Such NDT tests should be performed on 100% of the seamed geomembrane.

Shown in Table 1 are the available NDT seam testing methods which will be reviewed briefly.

Air Lance

The air lance method uses a jet of air at approximately 50 lb/ in.² pressure coming through an orifice of 3/16 in. diameter. It is directed beneath the upper edge of the overlapped seam to detect unbonded areas. When such an area is located, the air passes through, causing an inflation and fluttering in the localized area. The method works best on relatively thin flexible geomembranes,

 Table 1

 Available NDT Methods for Evaluating FML Seams, Modified from Frobel³

							Electronic	
Geomembrane system	Air lance ^a	Vacuum chamber ^b	Pressurized dual seam	Electrical sparking ^C	Mechanical point stress	Ultrasonic pulse echo (5-15 MHz)	Ultrasonic shadow (0.5-5 MHz)	Ultrasonic impedance (160-185 kHz)
Thermoplastics (PVC, TN-PVC; EIA)								
Reinforced Nonreinforced	X X	x x			X X	x	x x	x
Crystalline thermo- plastics (LDPE; HDPE)								
Nonreinforced		х	х	х	х	х	х	х
Elastomers (Butyl; EPDM; CR; CO)								
Reinforced Nonreinforced	X X	x x			x x		x x	
Thermoplastic elastomers (CPE; Hypalon; T-EPDM)								
Reinforced Nonreinforced	x x	x x			x x	x	x x	x x

^a Air lance should be restricted to thickness less than 45 mils; this method is not recommended for stiff sheeting.

^c Electronic methods do not work on EIA material.

b Vacuum chamber should be restricted to 30 mils and greater due to deformation.

but it works only if the defect is open at the front edge of the seam, where the air jet is directed.

Vacuum Chambers

Vacuum chambers (boxes) have been used where a box 3 ft. long with a transparent top is placed over the seam and a vacuum of approximately 2.5 $lb/in.^2$ is applied. When a leak is encountered, the soapy solution originally placed over the seam shows bubbles. These bubbles are due to air entering from beneath the liner and passing through the unbonded zone. The test is slow to perform, and it is often difficult to make a vacuum-tight joint at the bottom of the box where it passes over the seam edges (especially those encountered in thick HDPE geomembranes).

Pressurized Dual Seam

The pressurized dual seam method is one where two parallel seams are made with $\frac{1}{2}$ in. air space between them. This continuous air channel is inflated to approximately 30 lb/in.² for a length of 100 to 200 ft. If no drop in pressure occurs, the seam is acceptable; if a drop does occur, a number of alternatives can be followed.

- The distance can be systematically halves until the leak is located and repaired
- The difficult section can be tested by some other leak detection method
- A cap strip can be sealed over the entire edge

Electric Sparking

Electric sparking is an old technique used to detect pinholes in thermoplastic liners. The method uses a high-voltage (15 to 30kV) current and any leakage to ground (through an unbonded area) will result in sparking. The method is not very sensitive to overlapped seams of the type generally used in modern liners and currently is used only in rare instances. A new variation of the method is to embed a wire in the seam itself and test through the bonded zone.

Mechanical Point Test

The mechanical point stress or "pick" test uses a dull tool (such as a blunt screw-driver) under the top edge of an overlapped seam. With care, an individual can detect an unbonded area which is easier to lift than a properly bonded area. It is a rapid test but obviously depends completely on the care and sensitivity of the person doing it. Detectability is similar to that using the air lance. Both tests are very operator dependent.

Ultrasonic Pulse Echo

Electronic techniques are the newest of the methods used to evaluate seam integrity. The ultrasonic pulse echo technique is basically a thickness measurement technique and is only for use with nonreinforced FMLs like HDPE. Here a high-frequency pulse (of about 0.1 u sec duration and center frequency a few megahertz) is sent into the upper geomembrane and (in the case of good seam) reflects off of the bottom of the lower one. If, however, an unbonded area is present, the reflection will occur at the unbonded interface. Fig. 2 is a schematic diagram of the pulse echo method with results for "good" and "bad" seams. Fig. 3 shows actual data from a 30-mil hot air welded HDPE seam, where the pick penetration was 15/16 in. An echo from one single geomembrane thickness is seen whenever the transducer is less than 15/16 in. from the edge of the seam, and an echo from two geomembrane thicknesses is seen whenever the transducer is more than 15/16 in. from the edge.

Ultrasonic Shadow

Related to the pulse echo method is the ultrasonic shadow technique which uses similar equipment (although with physically separated transducers) but transmits a long pulse (about 50-100 µ sec)



Figure 2

Schematic Diagram of the Pulse Echo Ultrasonic Methods Used in Testing Flexible Membrane Liner Seams. Pictorial Representations of the Response of a "Good" and "Bad" Seams are Given.



Figure 3 Actual Data Using the Pulse Echo Ultrasonic Method. The Results are the HDPE of 60-mil Thickness. The Pick Penetration in this Case was 15 '16-inch. Note the First Echo Wherever the Pick Penetrates.

of ultrasonic energy rather than a short pulse. In this method, a good seam will convey most of the energy, while a poor or bad seam will convey little or none of it. By comparing received signals on a CRT screen, a qualitative seam assessment can be made. Fig. 4 shows a schematic diagram of the shadow method and the results for "good" and "bad" seams. Fig. 5 shows actual data for extrusion welded HDPE seams of 30 to 60 mil thickness. The varying amplitude of response indicates varying seam quality.

Ultrasonic Impedance Plane

The ultrasonic impedance plane method functions on the principle of acoustic impedance. A continuous wave of 160 to 185 kHz is sent through the seamed liner, and a characteristic dot pattern (representing the tip of the acoustic impedance vector) is displayed on a CRT screen. Calibration of the dot pattern is re-



Schematic Diagram of the Shadow Ultrasonic Method Used in Testing Flexible Membrane Liner Seams. Pictorial Representations of the Response of a "Good" Seam and a "Bad" Seam are Given.



Figure 5 Actual Data Using the Shadow Ultrasonic Method. The Results are for HDPE of 30 and 60-mil Thickness.

quired to signify a good seam; if the dot falls away from the calibrated position, a bad seam is indicated. Fig. 6 is a schematic diagram of the ultrasonic impedance plane setup, with the dot position indicated for good and bad bonds. The method has potential for all types of geomembranes but still needs additional development work. The authors of this paper have not worked directly with this method.

The pulse echo and impedance plane methods can be used only on surfaces that are reasonably flat, whereas the shadow method works on all types of seams. Many (not all) extrudate welds have a "bead" and are not at all flat, while the hot air and hot wedge seams are quite flat.

In closing this section of the paper, it should be mentioned that none of the tests described has been standardized by ASTM, NSF or other like body. Hence, testing of field seams is not consistent from one job to the next.



Schematic Diagram of Ultrasonic Impedance Plane Method Used in Testing Flexible Membrane Liner Seams. Pictorial Representations of the Response of a "Good" and "Bad" Seam are Given.

Ca

Indicating Unb

CONCLUSIONS

Upon reviewing the numerous comments suggesting the use of NDT field testing of geomembrane seams, the lack of published information regarding ultrasonics and other NDT methods is surprising. For example, a recent conference in West Germany on FML lined hazardous waste landfills' cites the potential use of ultrasonics ten times but never gives data (except one small descriptive figure like Fig. 2) and gives no references on the subject. Also, no data or references are given for any of the other NDT techniques.

Peggs^{8, 9} has presented work on the shadow method and Spanner¹⁰ has reported on work with the impedance method. Two other references^{11, 12} also are available using the shadow method, but do not apply directly to geomembranes. Certain companies claim to use pulse echo ultrasonics "routinely" on geomembrane field seams, but no data are available showing the statistical correlation of their results to other direct measures of seam integrity.

At present there is no NDT method which has the necessary background research and data to qualify it as a bonafide, reliable geomembrane seam testing device. In the authors' opinion, the ultrasonic techniques offer the best potential for a true NDT method. The ultrasonic methods alone, of all the NDT methods described, can be used at a rate fast enough (10 to 20 ft/min) to inspect 100% of the seams at a typical field site in a reasonable length of time. Operation subjectiveness and error are reduced considerably using ultrasonic methods compared to the other NDT methods. Ultrasonics can be used on all types of seams, and the shadow method can be used around connections and appurtenances. "Hard copy" can be produced and real-time audio alarms can be actuated over a defective area.

Desperately needed is a detailed experimental program where the results of ultrasonic methods are correlated with other important seam parameters such as:

- Seam strength
- Seam elongation at failure
- Seam permeability
- Seam mode of failure

This is a very ambitious task, but of extreme importance when one considers the effects of leakage of a lined landfill, waste pile or surface impoundment.

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Attenuating Contaminant Migration with Neutralizing and Sorptive Admix Barriers

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ABSTRACT

The milling of uranium ore produces large quantities of acid waste (mill tailings) that are deposited in earthen pits or repositories. These wastes, which remain potentially hazardous for long time periods, may reach the biosphere at levels greater than those allowed by the U.S. EPA. As a result, technologies must be developed to ensure that such wastes will not reach the biosphere at hazardous levels.

Pacific Northwest Laboratories (PNL) investigated the use of various neutralizing reagents and techniques and the use of engineered barriers to attenuate the movement of contaminants associated with acidic mine waste. The objective of this study was to identify the contaminants that are, and are not, effectively attenuated by common neutralization methods. For those constituents not effectively attenuated by neutralization, our objectives also included developing and testing alternative control measures such as specific ion removal techniques. Results of these investigations led to the development of: (1) a low permeable, neutralizing barrier composed of lime and coarse-grained sediment, and (2) tailings additive comprised of a mixture of lime and barium chloride, which, when added to acidic tailings, can reduce the amount of leachable radium escaping a designated tailings impoundment.

The barrier was developed as a low-cost alternative to clay liner schemes for use in areas where clays were not locally available and must be shipped to the disposal site. In laboratory verification tests, the neutralizing and sorptive barrier reduced the effluent solution concentration of several constituents (e.g., Al, As, Cr, Fe, V, total Ra,²¹⁰Pb, ²³⁰Th and total dissolved solids) by greater than 90% in comparison to concentrations found in untreated leachate samples. Furthermore, the neutralizing and sorptive barrier inhibited drainage resulting from permeabilities on the order of 10^{-8} cm/sec.

INTRODUCTION

In 1981 the Nuclear Regulatory Commission expanded the scope of the uranium research program at PNL to address the use of tailings neutralization for immobilizing toxic materials in acidic uranium mill waste. The objective of this project was to assess viable alternatives for reducing contaminant mobility under a full range of site and environmental conditions. Laboratory experiments were performed to test various neutralizing agents, to evaluate their performance and to optimize treatment conditions for contaminant immobilization.^{2,3,4} The results of these batch treatment experiments indicated that calcium alkalies [CaCO₃ and Ca(OH₂] provide the highest quality neutralized effluent at the lowest cost.

The neutralization process is very effective in attenuating a high percentage of the dissolved constituents contained originally in

acidic UMT solutions. However, certain constituents commonly associated with tailings solution are not strictly dependent on solution pH for their solubility in uranium tailings liquors. Therefore, the activities or concentrations of these constituents show only slight and sometimes no attenuation after solution neutralization. One of these constituents not ideally controlled by neutralization is radium.

Control or attenuation of radium is of special concern primarily because of its radiological health implications. Current U.S. EPA guidelines call for total radium activities not to exceed 5 pCi/L. Due to the high activity of soluble radium in the acidic UMT environment (several hundred to several thousand pCi/L), specific ion removal procedures were investigated for use in attenuating radium in order to prevent future groundwater contamination.

In this study, we performed further laboratory tests using lime neutralization. In these tests, lime was mixed as an additive into overburden material from the Exxon Highland mill site in Converse County, Wyoming. The study's objective was to test a method of amending coarse-grained materials to improve their ability to retard contaminant migration.

In addition, we performed laboratory tests using lime neutralization plus barium addition (in the form of barium chloride) to the tailings directly. These tests evaluated a method of amending solid acidic tailings in order to attenuate the migration of contaminants from the waste source and reduce the potential for future groundwater contamination.

MATERIALS AND METHODS

For the purposes of assessing the performance of the barriers, columns of both overburden and tailings were compacted with and without chemical amendments. The calcium hydroxide amendment was mixed into the tailings as an oven-dried solid.

Table 1 Description of Columns Containing Overburden and Tailings						
Column ID Description						
1	1000 g tailings, 7.3 g Ca(OH) ₂ 151 mL BaCl ₂ solution.					
2	1000 g tailings, 151 mL DD H ₂ 0.					
3	1000 g overburden, unamended, high density					
4	1000 g overburden, 50 g Ca(OH) ₂ , high density					
5	1000 g overburden, unamended low density					
6	1000 g overburden, 50 g Ca(OH) ₂ , low density					

Barium chloride was added to the tailings in liquid form after dissolving 3.286 g/l of $BaCl_2 - 2H_2O$ in distilled, deionized water (DD H₂O). Distilled deionized water only was added to the untreated tailings not containing barium chloride. The descriptions of the amended and the untreated tailings columns are shown in Table 1.

Once compacted, the columns containing the amended tailings mixtures and the untreated tailings were leached with local groundwater. The columns containing the amended and untreated overburden were contacted with Exxon tailings solution as collected from the tailings solution pond. The chemical compositions of the local groundwater and the tailings solution are shown in Table 2.

Table 2 Groundwater and Tailings Solution Chemical Composition

	Local	Tailings
Parameter	Groundwater (mg/1)	Solution (mg/l)
A1	0.1	440
As	<0.02	0.21
Ba	0.03	<0.1
Ca	25.1	560
Co	ND ^(a)	1.31
Cr	ND	1.25
Cu	ND	0.97
Fe	0.04	1000
ĸ	0.9	44
Ma	4.4	540
Mn	<0.3	50
Na	2.9	340
Se	ND	1.35
51	3.6	310
Zn	0.2	4.5
CI	1.5	300
S0.	19.8	9300
Total dissolved		
solids (q/l)	0.6	12.9
pH	8.2	1.9
(a) ND - Not Dete	ermined	

RESULTS

Radium Attenuation Experiments

The results of the radium attenuation experiments, which compare the untreated tailings with the amended tailings, are shown in Fig. 1. The first sample collected from the untreated acidic tailings at an adjusted pore volume of 0.51 contained 3345 pCi/L of soluble radium. As local groundwater contact continued, the activity of the radium leached from the acidic tailings decreased to 1218 pCi/L after 1.6 pore volumes of leaching. The final sample collected in these experiments contained 570 pCi/L at an adjusted pore volume of 2.8, still over two orders of magnitude higher than the U.S. EPA's drinking water limit of 5 pCi/L total radium. The amended tailings column [neutralized with Ca(OH), plus BaCl, added] displayed a high degree of radium attenuation throughout the duration of the experiment. The initial radium activity in the sample collected at an adjusted pore volume of 0.6 was 1.7 pCi/L. This decrease represents a reduction in total radium activity of greater than three orders of magnitude compared to the first sample collected from the untreated acidic tailings. With continued leachant contact, the radium activity showed an additional reduction to 1.1 pCi/L at 1.72 adjusted pore volumes. The last sample collected from the amended tailings column displayed a slight increase in radium activity. At an adjusted pore volume of 2.8, 6.1 pCi/L of soluble radium were detected in the column effluent. Although the final sample collected from the amended tailings column was 1.1 pCi/L higher than the U.S. EPA's drinking water limit, a value of 6.1 pCi/L represents a decrease of nearly two orders of magnitude over the untreated tailings column at similar leaching volumes.



Fig. 1 Results of Treated and Untreated Tailings Experiments

The mechanism that accounts for the removal of soluble radium from the tailings effluent solution is assumed to be coprecipitation. The reactants in the amended tailings material are $BaCl_2$ and radium from the acidic tailings. The reaction is shown in equation (1) and is probably the most common method for radium removal from solution.³

$$BaCl_{2} + Ra^{2+} + SO_{2}^{2-} = 2 Cl^{-} + (Ra, Ba)SO_{4}$$
 (1)

As barium sulfate is precipitated, radium is effectively removed from solution by adsorption onto the precipitate surface or is incorporated into the lattice structure of the solid precipitate. Radium removal is very much dependent on the solution parameters associated with the precipitation reactions. For example, there must be an excess of sulfate in solution and the kinetics of the co-precipitation reaction are sometimes slow so adequate column residence time or reaction time (ranging from hours to days, dependent on conditions) is necessary.^{5,6} Since most U.S. mills use a sulfuric acid leach cycle, excess sulfate typically is present. Furthermore, by neutralizing the acidic tailings, the reactants (BaCl₂ and radium) are retained in the column long enough for the reaction to occur.

Tailings neutralization causes the pH-dependent ions to precipitate in the pore spaces within the column. The solids formed plug the pathways through which solution normally travels, reduce the flow rate of leachant through the neutral tailings and, therefore, increase the residence time for reactions.

Permeability and Leaching Experiments

The calculated permeability values for both the untreated Exxon overburden and the overburden with 5% lime versus the number of pore volumes of effluent tailings solution are plotted in Fig. 2. The graph indicates permeabilities were nearly identical at the start of the experiment. The untreated overburden displayed permeabilities in the range of 4×10^{-6} cm/sec to 1×10^{-6} cm/sec during contact with approximately 24 pore volumes of acidic tailings solution. The Exxon overburden with 5% lime displayed an initial permeability of 3.5×10^{-6} cm/sec followed by a rapid decrease in column flow rates as contact with acid tailings solution continued.



Figure 2 Permeability vs. Pore Volume Comparison Between Untreated and Treated Overburden (with lime)

After interaction with approximately four pore volumes of tailings solution, the permeability of the lime-treated overburden decreased over one order of magnitude to 5×10^{-7} cm/sec. After 20 pore volumes of acidic solution contact, the permeability decreased to 4×10^{-8} cm/sec and remained at that flow rate until a total of 24 pore volumes of uranium tailngs solution had contacted the lime-treated Exxon sediment. This final permeability represents a decrease of two orders of magnitude over the course of 24 pore volumes of acid solution contact.

Solution Chemistry

The chemical compositions of the effluents collected from both the untreated acidic tailings and the amended tailings columns are shown in Table 3. The data indicate that in addition to a substantial reduction in total radium activity, similar reductions were

 Table 3

 Solution Compositions of Untreated and Treated

 Tailings Effluent

	1	Untreated			Amended			
	1	2	3		2	3		
pH	2.40	2.65	2.77	6.52	7.31	7.66		
Adjusted pore volume	0.52	1.64	2.77	0.60	1.72	2.84		
Total dissolved solids (o/l)	7.22	2.46	1.70	3.25	1.35	1.04		
Total radium (pC1/1)	3345	1218	570	1.7	1.1	6.1		
Macro 1ons (mg/1)								
A1	2100	570	300	<10	<10	<10		
As	2.82	0.76	0.43	<0.02	<0.05	<0.02		
Ba	<0.06	<0.02	<0.02	<0.04	<0.02	<0.02		
Ca	610	560	610	1020	660	660		
Co	5.33	1.22	0.83	0.06	<0.02	<0.02		
Cr	2.70	0.89	0.55	<0.01	<0.01	<0.01		
Cu	2.69	0.76	0.34	<0.02	<0.02	<0.02		
Fe	1400	390	240	<10	<10	<10		
Mg	1740	472	254	1120	391	202		
Mn	197	50	26	36	19	14		
Na	1000	360	230	1070	280	160		
Se	0.24	<0.03	<0.02	0.22	<0.05	<0.05		
ST	60	34	30	<10	5	6		
Zn	32	7.8	<5.0	<5	<5	<5		
C)	510	170	90	3860	565	140		
SO ₄	25600	8100	5000	3430	2780	2630		

detected for several of the macro cations, trace metals and sulfate in the column effluents. Elements such as Al, As, Cr, Cu, Co, Fe, Si, Zn and the sulfate ion all exhibited large decreases relative to their original concentration in the untreated tailings column effluents. These reductions are attributed to the change in solution pH (acidic to neutral) during which time the solubility of the above elements is exceeded resulting in precipitation reactions. For sulfate, the reduction in solution concentration is due to the formation of gypsum (CaSO₄ $- 2H_2O$) when the free sulfate reacts with the Ca ion upon the addition of lime. The reaction products that form during the pH change are mainly metal hydroxides from the Ca(OH)2 added and sulfate salts as indicated by the large decrease in soluble ions detected in the effluents as reported in Table 3. As mentioned previously, the metal hydroxide and sulfate precipitates plug the solution pathways and reduce the flow rate of leachant through the neutral tailings. By limiting or reducing the solution flow through tailings, the leaching of contaminants not attenuated by either neutralization or barium addition also is reduced.4

The chemical composition of the acidic UMT solution used as the column influent solution and the effluent solutions collected from both the untreated and treated (with 5% lime) overburden are shown in Tables 4 and 5, respectively. The acid breakthrough curves (pH versus pore volume) for both sediments (columns 5 and 6) are shown in Fig. 3. The initial column effluent data from

 Table 4

 Solution Composition of Untreated Exxon Overburden Column

	Effluent #				Tailings
		2	3	4	Solution
рH	7.5	7.3	3.7	3.0	1.9
Pore volume	1.6	2.9	4.7	7.3	
Total dissolved solids (g/i)	4.71	5.1	9,84	13.66	12.9
Macro ions (mg/l)					
Al	3.1	0.4	161	694	440
As	<0.01	<0.01	<0.01	0.25	0.21
Ba	0.12	0.20	0.06	0.09	<0.1
Ca	940	898	659	507	560
Co	<0.02	<0.02	2.47	1.4	1.31
Cr	<0.01	0.04	0.08	0.05	1.25
Cu	<0.02	0.09	0.05	0.06	0.97
Fe	<0.1	<0.1	65.8	1580	1000
Ma	249	228	837	532	540
Mn	<0.2	0.9	144	49.8	50
Na	139	324	354	342	340
Se	0.64	0.74	0.68	0.89	1.35
S1	7.0	5.8	70	283	310
Zn	<0.1	<0.1	3.0	6.5	4.5
C1	195	325	315	325	300
so ₄	3159	3262	7161	9305	9300

 Table 5

 Solution Composition of Treated Exxon Overburden Column

		Tailings			
		2	3	4	Solution
рH	12.8	12.8	12.8	12.8	1.9
Pore volume	1.84	5.2	11.2	17.9	
Total dissolved solids (g/l)	3.0	4.9	3.97	4.67	12.9
Macro ions (mg/l)					
A1	0.7	0.6	0.1	0.7	440
As	<0.02	<0.02	<0.02	<0.02	0.21
8a	0.21	0.10	0.10	0.28	<0.1
Ca	760	1044	1294	1475	560
Co	<0.02	<0.02	<0.02	<0.02	1.31
Cr	0.09	0.28	0.10	0,06	1.25
Cu	0.23	0.14	0.10	0.06	0.97
Fe	<0.1	<0.1	<0.1	<0.1	1000
Mg	0.3	2.5	0.5	1.3	540
Mn	<0.1	<0.1	<0.1	<0.1	50
Na	239	384	345	332	340
Se	0.07	1.43	1.16	0.98	1.35
51	2.6	7.4	<0.1	1.1	310
Zn	<0.1	<0.1	<0.1	<0.1	4.5
C1	275	330	340	315	300
S04	1700	2867	1974	2527	9300

both the untreated and treated overburden indicate a substantial reduction in solution constituent concentrations. The total dissolved solids (TDS) content in the effluent from the untreated sediment column after 1.6 pore volumes of solution contact was reduced by 63%, while the lime-amended sediment showed reductions greater than 76% after 1.8 pore volumes of solution/sediment interaction.

The reduction in solution consistent concentration can be attributed to two mechanisms: sediment adsorption interactions and, more importantly, precipitation reactions caused by influent solution neutralization. High concentrations of macro ions (i.e., Al, Fe, Mg, Mn, Si and SO₄) and trace metals (i.e., As, Co, Cr, Cu and Zn) in the very acidic (pH 1.9) tailings solution exceed their solubility limit and form precipitates as the solution approaches a neutral pH. The effects of solution neutralization continue until the sediment's buffering capacity is expended (primarily the dissolution of CaCO₁ contained in the sediment).



Acid Breakthrough Curves for Untreated and Treated Overburden

The acid breakthrough curves shown in Fig. 3 illustrate the ability of the untreated overburden to buffer several pore volumes of acidic uranium tailings solution. In the case of the overburden with no lime, approximately four pore volumes of tailings solution contacted the sediment before the buffering capacity was expended. As solution contact continued, the effluent solution pH decreased rapidly (higher acidity), and after a total of five pore volumes of acid solution contact, the effluent solution was approximately pH 3.5.

Data for the effluent from column 5 (untreated overburden) in Table 4 shows the TDS content approaching that of the influent solution after 4.7 pore volumes of contact. After 7.3 pore volumes of tailings solution interaction, the effluent solution was pH 3.0 and had begun to redissolve part of the initially formed precipitates, as indicated by the TDS content and individual constituent concentrations being higher than originally present in the influent solution.

The treated Exxon overburden representing the neutralizing barrier exhibited a much greater buffering capacity because of the addition of 5% lime. The acid breakthrough curve, as shown in Fig. 3, illustrates how an increase in buffering capacity significantly increased the ability of an existing sediment to retard contaminant migration via neutralization reactions. After 15 pore volumes of tailings solution contact, the effluent solution from the lime-amended sediment column remained highly alkaline (pH 12.8). In addition, the solution constituent concentrations and/or TDS content continued to be significantly reduced (see Table 5).

The data for the four effluents analyzed (Table 5) demonstrate the barrier's capability to reduce the guantities of dissolved solids in effluents from uranium tailings ponds. Effluent #4 (Table 5) has 4.67 g/l TDS remaining in the effluent solution after 17.9 pore volumes of contact (reduced 63% from influent levels). In other words, approximately 8.2 g/l (influent dissolved solids minus effluent dissolved solids) of precipitates continue to be deposited within the column sediment. After 17.9 pore volumes of solution contact (268 mL/pore volume as per Table 1), approximately 41 g of precipitated solids were deposited in the limeamended sediment. In effect, the deposition of the solids gradually increased the column's overall bulk density (1.39 g/cm³ to 1.46 g/cm^3) and therefore decreased the porosity (0.49 to 0.46) of the compacted sediment. The gradual accumulation of precipitates, deposited within the pore space of the sediment, plugs the pathways through which solution normally migrates and results in a decrease in sediment permeability (such as observed in Fig. 2) as tailings solution/sediment interaction continues.

CONCLUSIONS

The results of these tests indicate that barium chloride addition to tailings can effectively limit the amount of soluble radium leached from acidic uranium mill tailings. Initial radium activities in the untreated acidic tailings (0.52 pore volumes) were greater than 3300 pCi/l. After 2.8 pore volumes of leaching, the radium activities were 570 pCi/l; still greater than two orders of magnitude higher than the U.S. EPA's water standard of 5 pCi/l. At similar pore volumes, the radium activity of the bariumtreated tailings was 1.7 pCi/l(0.60 pore volumes); equivalent to a reduction by a factor of greater than 1900. At 2.8 pore volumes, the radium activity was 6.1 pCi/l; a reduction of nearly two orders of magnitude.

The results of the overburden amendment studies indicate that a neutralizing barrier comprised of a sandy loam material and lime can be an effective barrier to acidic seepage. Dissolution of lime within the barrier not only buffers the acidity, but also provides a source of calcium for the precipitation of sulfate as gypsum (CaSO₄ - 2H₂O). The removal of soluble sulfate from the effluent constitutes the major portion of the TDS reduction. Precipitation of nearly two-thirds of the influent TDS content was maintained in the neutralizing barrier columns through the 17th pore volume, whereas the untreated overburden columns eluted a higher TDS content than the influent after only about 7 pore volumes.

Tailings treatment techniques such as barium chloride/hydrated lime treatment and neutralizing barriers effectively reduce the TDS content, the trade contaminant content and the velocity at which effluent can seep. Using such a barrier appears to be a viable alternative for limiting the migration of acidic seepage through coarse-grained sediments and geologic formations.

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Geomembrane Barrier Technology For Superfund Cleanup

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ABSTRACT

Superfund cleanup work requires careful consideration of the latest developments in barrier technology. High quality geomembranes have proven very useful in dealing with the monumental problems posed by toxic and hazardous wastes. This paper deals with issues of material selection in barrier technology and reports on the emerging options for barrier wall construction with geomembranes.

INTRODUCTION

The Superfund program has taken a first step toward solving one of the most perplexing environmental challenges of all time, i.e., improper past disposal of hazardous waste. The true cost of past waste disposal practices is confronting this country as a vivid reality, and billions of dollars are being set aside for cleaning up the environment. Since we did not pay to properly dispose of the waste before, we are paying now.

But what are proper waste disposal techniques? Many people talk about waste recycling or incineration as though they are the panacea to the hazardous waste problem. Yet neither solution is a complete answer; quite hazardous non-reusable waste and ash still remains. The above-cited methods are suitable only for certain wastes. Deep-well injection, another viable disposal technique, also has limited application, in this case to certain liquid wastes. The simple truth is that disposal and containment of waste products on the earth's surface must continue for lack of a better alternative.

Since surface containment of waste is necessary, the most real-





istic approach is to provide the best possible barrier for waste containment. If money is spent on appropriate barriers to waste migration, savings result because future cleanup operations become unnecessary. Also, if costs are increased for traditional surface containment because of better barrier construction, desirable alternatives such as recycling become more cost-competitive. Incentive therefore develops to conserve and recycle waste.

The U.S. EPA has recognized the importance of improving the barriers to waste migration in hazardous waste containment. In November of 1984, RCRA was modified to contain more rigorous minimum technology requirements for land disposal facilities. Certain landfills and surface impoundments now are required to have "two or more liners and a leachate collection system above (in the case of a landfill) and between such liners" (Fig. 1).

DEVELOPMENT OF BARRIERS FOR WASTE CONTAINMENT

Over the years, a number of different types of materials, both natural and synthetic, have been available for use as barriers in waste landfills and impoundments:

- Clay
- Bentonite Clay
- Bentonite Slurry Walls
- Cement Stabilized Sand
- Bitumen
- Asphalt
- Grout Curtains
- Steel Sheet Pilings
- Flexible Membrane Liners (FMLs)
- Butyl Rubber Chlorinated Polyethylene (CPE) Chlorolsulfonated Polyethylene (CSPE-Hypalon) Epichlorohydrin Rubber (ECO)
- Ethylene Propylene Rubber (EPDM)
- Ethylene Propylene Terpolymer (EPT) Low Density Polyethylene (LDPE) High Density Polyethylene (HDPE) Neoprene (Chloroprene Rubber) Polyvinyl Chloride (PVC)
- Thermoplastic Elastomers

Clays, including bentonite (which swells to increased impermeability when in contact with water), had proven the most practical and popular. Permeability studies, however, have shown that certain alkaline solutions and hydrocarbons can seriously affect the impermeability of clays.^{2,3}

Conventional clay permeability tests using water with 0.01 N CaSO4 qualify most clay soils for lining hazardous waste disposal facilities on the basis of their having permeabilities lower than 1 x 10^{-7} cm/sec. However, when the same clay soils are subjected to permeability tests with solutions of organic fluids, they undergo large permeability increases exceeding permeabilities of 1 x 10^{-7} cm/sec. Reintroduction of plain water does not return the soil to its original permeability, thus implying some structural alterations caused by the interaction of organic chemicals with compacted clay soil. This change in permeability is believed to be due to the organic fluids tending to pull the soil particles in the clay into aggregations of many particles resulting in the formation of large interconnected pores.

Acidic or basic leachate also has been found to disrupt clay barriers with permeability increases.⁴ The mechanism in this case is dissolution of the soil binding agents in the clay followed by movement of the clay particles out of the barrier.

In addition, the actual field permeability of compacted clay liners apparently greatly exceeds laboratory measured clay permeabilities. Laboratory permeability tests do not take into account the presence of cracks, fissures and inter-clod voids which appear by virtue of the larger scale in the field.³ Cement stabilized sand can also crack, especially in the presence of acidic conditions.

Steel sheet piling will rust, especially in the presence of acids.

Synthetic flexible membrane liners (FMLs) are therefore highly attractive because of their negligible permeability and good chemical resistance. As can be seen from the previous list of potential materials used as liners, many different polymers have been used in geomembranes. Only a few, however, have achieved widespread use for applications in which fluid containment is absolutely critical-such as for containment of hazardous chemical wastes. Only a few have the long-term durability to withstand harsh environment for many years. In the short history of FMLs, the industry has been quick to adopt the most appropriate polymeric material for waste containment available. This means that the most commonly used polymeric material for FML manufacture has changed as polymer technology has progressed. In the same way that the airplane industry's choice material of construction has gone from wood to aluminum, the waste containment industry's choice material for FMLs has gone from butyl rubber to high density polyethylene (HDPE). This historical progress is displayed in Fig. 2.



Life Cycle of the Most Commonly Used Chemically Resistant Synthetic Liners

With the advent of copolymer pipe grade HDPE technology, geomembranes can now boast of strength, toughness, durability, chemical resistance and environmental stress crack resistance. The qualities of HDPE as a barrier material are also increasing its applications in the container market. Much growth is expected for HDPE containers of agricultural chemicals, insecticides, herbicides, paint thinners, household chemicals and other chemical products.⁶ HDPE is expected to replace more and more traditional metal and glass containers in the market place.

Advances in HDPE resin technology are responsible for its increased use as a barrier membrane for chemicals; hence, its increased (and almost exclusive) use in geomembranes for hazardous waste landfills and surface impoundments. But to provide maximum barrier protection, the proper grade of HDPE should be utilized. For instance, linear low density polyethylenes (LLDPE) also utilize the new copolymer technology, as do the pipe grade HDPE resins. Yet, because of their lower density and molecular weight, they do not provide the chemical resistance, strength and durability that the pipe grade HDPE resins do. To test their respective barrier performances, the chemical immersion test described in the next section was performed on copolymer HDPE and LLDPE.

CHEMICAL RESISTANCE STUDY

Chemical immersion testing of geomembranes presently is required by the U.S. EPA before approval of new hazardous waste facilities is granted. The protocol for testing is outlined in U.S. EPA Method 9090. Because of such routine testing, in addition to data generated by the resin manufacturers, there exists a considerable volume of information regarding the chemical resistance of HDPE.

Apart from a few strong oxidizing acids, there are few chemicals which damage pipe-grade quality copolymer HDPE materials. Organic solvents may be absorbed into the liners causing some softening with a corresponding decrease in physical property performance. However, they do not actually degrade the HDPE.

Degradation of a geomembrane liner is interpreted as an irreversible process in which useful polymer properties degenerate when exposed to the environment. The degradation takes place because of the rupture of primary and secondary chemical bonds in the polymer matrix. Chemical species as well as energy sources cause the destruction of polymer bonding.⁷

As a part of this study, a chemical immersion test was conducted. Sixty mil thick (1.5 mm) pipe-grade quality copolymer HDPE geomembrane liner was immersed in 100% dichloroethylene. The chlorinated hydrocarbon was chosen because of reportedly degradative action on HDPE. U.S. EPA Method 9090 provided the test procedure pattern for the chemical resistance testing. The test differed from the U.S. EPA method in that sample specimens for testing were cut prior to immersion. This allowed more liner contact with hazardous solvents and a reduced volume of solvent necessary for testing. Testing was continued for 150 days instead of the 120 days required by the U.S. EPA. The following tests were performed:

Test	Method
Tensile Properties	ASTM D638, Type IV Specimen 2 ipm
Initial Tear Resistance	ASTM D1004, Die C
Puncture Resistance	ASTM 101B, Method 2065
Weight Change	1 x 3 in. Specimen
Thickness Change	1 x 3 in. Specimen

Two temperature conditions were maintained for each chemical solvent in the study; 23 °C and 50 °C (as per Method 9090). Tables 1 and 2 list the results of the study. Sample specimens were cut both parallel to machine direction as well as perpendicular to machine direction in order to check any possible polymer orientation effects. Three specimens were tested for each line entry in Tables 1 and 2. Specimens were checked at 60, 100 and 150 day intervals. The averaged results and percent change in test property values are recorded in the tables.

There are no well-defined standards to determine if the results from a Method 9090 type immersion indicate if the liner "passed" or "failed." But, after examining the results in Tables 1 and 2, we can make the following remarks. The sample specimens seem to have stabilized in the dichloroethylene by the first sampling period (60 days). For dichloroethylene, any reaction with the HDPE appears to have ceased. In fact, the change may well be due to absorption of solvent only, without chemical reaction.

These conclusions are confirmed by the results of thermaloxidative stability testing of the liner at the 60, 100 and 150 day intervals of immersion. Thermal-oxidative stability testing is a convenient and practical approach to determine the extent to polymer degradation in geomembrane liners. High temperatures and highly reactive oxygen are combined in thermal-oxidative stability testing in order to accelerate the reactions responsible for the destruction of polymer bonding. If degradation has taken or is taking place, then thermal-oxidative stability testing will indicate a degraded condition in the sample because of reduced stability to thermal-oxidative conditions.

Table 1
Fensile Properties Testing Over 150 Days of Immersion in
Dichloroethylene

60 HIL ROPE AT 23"C

ND	TIELD STRENGTH (PSI)	YIELD ELONGATION (1)	BREAK STRENCTH (PSI)	BREAK ELONGATION (1)
Control	2\$32	15	4581	825
60 Days	2589	17	4905	905
I Change	-0.6	+13	+7.l	+9.7
100 Days	2551	17	4897	885
I Change	-9.9	+(3	+7.6	
L30 Days	2582	17	4695	855
I Change	-4.5	+13.3	+2.5	+3.7
10				
Control	2908	13	4861	843
60 Days	2828	16	5252	900
I Change	-2.8	+6.7	• 4 .	+6.5
LOO Days	2657	17	5290	938
Z Change	-4.6	+13	+8.6	+11
LSO Days	269 L	15	4986	922
1 Change	-7.5	•	+2.6	+9.L
	<u>60 :</u>	CL DIE AT 50°C		
<u></u>				
Control	2432	15	4561	825
60 Days	2623	17	4807	948
I Change	-7.2	+13	+3	+15
100 Days	2425	17	4763	890
I Change	-14.4	+L)	ت نه	+7.9
150 Days	2544	17	4537	653
Z Citange	-9.5	+13-3	-1	+3.4
<u>.</u>				
Cunctol	1908	13	-361	3-3
60 Days	2674	17	÷903	863
I Change	-8.1	+13	+1	+2.4
100 Days	2566	17	5939	915
Change	+4.6	+13	+L.ő	+8.3
LSO DAYS	2670	17	5107	925
Change	+11	+[].]	+9.L	+9.5

MD-Sample specimens tested in machine direction of process manufacture

TD-Sample specimens tested in transverse direction to process manufacture.

In thermal-oxidative stability testing, since the reactions of polymer degradation are exothermic, rapid deterioration shows up on a differential scanning calorimeter (DSC) as heat flows out of the sample. The time at which these degradative reactions occur in a run-away fashion is therefore visible on the DSC by the heat released in the destructive reactions. The time which the sample requires to reach this run-away state of degradation is called the oxidative induction time (OIT). OIT therefore provides a convenient measure of how long the liner sample is able to withstand thermal-oxidative stress.

 Table 2

 Other Physical Properties Testing Over 150 Days of Immersion in Dichloroethylene

			VEICHT	CRUNCE AT 2	<u>).c</u>		
	Contral	60 Days	: Change	100 Dave	I Change	150 Days	I Change
110 110	2.8055 277131	2.9436 2.8469	+5 +1.5	2.9570	+3.4 +3.6	2.8636 2.7763	+2.2 +2.3
			VIICITI CIU	UCZ AT 50°C			
360 120	2.7043 2.6139	2.8456 2.7920	46.7 46.7	2.8837 2.7926	46.3 46.8	2.77L0 2.6610	+2.5 +2.5
			TRICTORS	CHANCE AT 2	<u>)*c</u>		
H\$D 127	. 056" . 0 54 "	.056" .057"	8 +L.8	.059" .057"	ન.ક ન.ક	.057** .057**	+1.8 +1.8
			TICOUS	CHANCE AT 50	* <u>c</u>		
HED ⁻ TD	.0 36" .056"	.057- .057-	+1.8 +1.8	.058" .057"	+].6 +1.8	.057** .057**	+L.8 +i_8
			TEAR LESIS	LUCE AT LIT	<u>c</u>		
760 TD	36 37	44 55	-14.3 +17	51 53	-8.9 +L)	52 53	-7.1 +13
			TEAR MESIST	ANCE AT 50"C	E		
19 19	36 47	49 3-	-12.5 +13	46 51	-L8 +8.5	4 9 54	-17.7 +13
PUNCTURE AT 23"C							
•	79	•3	-0.5	60	-24	63	-17.7
			PUNCTURE AT	50°C			
	n	64	* 9.8	60	-24	66	-16.5

MD-Sample specimens tested in machine direction of process manufacture.

TD-Sample specimens tested in transverse direction to process manufacture.

Table 3 displays results of thermal-oxidative testing of the pipe grade quality copolymer HDPE liner during chemical immersion testing at the intervals of the test. The OITs were run according to instrument manufacturer recommendations. A small sample of copolymer LLDPE liner was also tested for thermal-oxidative stability during chemical immersion alongside the HDPE.

Table 3 Chemical Resistance Comparison of Copolymer HDPE Liner to Copolymer LLDPE Liner by Measuring Changes in Stability Toward Thermal-Oxidative Degradation

	Dichloroethylene				
	OIT (minutes)				
Sample ²	Copolymer HDPE	Copelymet LLDPE			
Costrol	85	44			
60 Dey	90	IJ			
100 bay	91	20			
150 Day	90	20			
Pinal I Change	+5.92	-54.51			

¹ OIT (Oxidative Induction Time) determined by Differential Scanning Calorimeter @200 °C, 1 atm of 0₂.

¹ Samples immersed in chlorinated hydrocarbon at 23 °C.

The results of Table 3 indicated that the dichloroethylene does not actually degrade the HDPE. The HDPE retained its thermal oxidative stability in dichloroethylene. On the other hand, the LLDPE appears to have been degraded in the dichloroethylene, losing 55% of its stability. The importance of polyethylene resin selection in the manufacture of high quality geomembrane barriers was confirmed.

Because of their excellent chemical resistance properties, HDPE geomembranes are prime candidates for barriers to contain the toxic and hazardous wastes encountered in Superfund projects.

SUPERFUND CLEANUP STRATEGY

Every Superfund site requires its own special considerations before a cleanup strategy can be delineated. The goal, however, in every case is to prevent the toxic waste from migrating.

Current barrier technology can offer a number of practical approaches to site cleanup. These procedures can be generally classified into the following groups:

- Removal of the contaminated material off-site for containment in a RCRA-approved hazardous waste facility or treatment/cleansing of polluted soils
- Construction of an RCRA landfill at or adjacent to the site for transfer and proper containment of the polluted soil
- Construction of an impermeable cap and barrier wall for onsite waste containment to prevent infiltration of surface water/ precipitation and the spreading of contamination to the surrounding groundwater

Removal of contaminated material to a hazardous waste facility means the construction of increased capacity at RCRA-approved disposal sites.

Proper construction of a landfill at or adjacent to the Superfund site would also demand the double liner technology required by RCRA. All the considerations appropriate to hazardous waste facility construction centered around the installation of two layers of geomembrane would apply. These considerations are not unique to Superfund work and will not be dealt with in this article.

The construction of caps and barrier walls for on-site containment of Superfund waste likely will be a frequent strategy in cleanup work. The use of geomembranes for cap construction has been well-proven over a good many years. Barrier walls are now being made with geomembranes. Caps and barrier wall applications for Superfund work are discussed in some detail in this article.

CAP AND BARRIER WALL CONSTRUCTION USING GEOMEMBRANES

Superfund cleanup work at Nashua, New Hampshire, utilized a cap and barrier wall to meet a fast-moving plume of groundwater contaminated with organic solvents including chlorinated hydrocarbons. The contaminant plume was moving at a rate of about 2 ft/day when work began in 1982 and had to be halted right away. The 20-acre synthetic cap was constructed with an HDPE geomembrane liner, and the barrier cut-off wall was made from a bentonite slurry extending down to bedrock and ringing the site in an oval shape.



Figure 3 Schematic of Cap and Barrier Wall On-Site Containment System for Superfund Projects



Figure 4 Bentonite Slurry—HDPE Barrier Wall Combination



Figure 5 Barrier Wall Construction at Quincy, Illinois, with Gundline HD as the Impermeable Layer



Figure 6 Completed Barrier Wall at Quincy, Illinois

Because of fractures in the bedrock and because of evidence that the organic chemicals in the aquifer would tend to degrade the bentonite by altering the mineral composition of the clay, groundwater interception and treatment were implemented through the use of pumps. Contaminated water is thus being pumped out of the containment area, treated and reinjected so as to flush out remaining contaminants. This innovative and dollar-saving Superfund project at Nashua, New Hampshire, likely is indicative of the approach to be used at many sites in the future (i.e., cap and barrier wall construction with pumping of contaminated water to lower the water table within the containment and remove pollutants).

Construction of caps for Superfund cleanup could utilize other geosynthetics such as geonet for drainage of surface precipitation above the impermeable geomembrane layer as well as geotextile for separation of cover soil from the fluid flow zones.

HDPE geomembranes recently have found application in barrier wall construction in addition to their normal application in synthetic caps. The advantages they offer are apparent:

- Completely watertight
- Inherent flexibility to allow for settlement
- Suitable for installation in all types of soil
- · Resistant to decay, microorganisms, rodents and chemicals
- Simple, installation procedures

A new technique of locking together entire rolls of HDPE sheet is now available. The lock ensures a completely watertight joint to prevent leakage of contaminated groundwater. The sheets of HDPE equipped with the lock can be slid into place next to each other as a vertical barrier down to the clay/bedrock layer. They can be joined to a synthetic cap at the surface for isolation and containment of the toxic waste. Fig. 3 shows a schematic diagram of this approach. To create both inward and upward hydraulic gradients, thus further ensuring non-migration of the pollution, the water table within the containment can be lowered through the use of drainage wells. Contaminated groundwater flowing into the drainage wells then can be treated and separated, and the waste can be properly disposed.

Barrier wall construction with HDPE can be applied in conjunction with bentonite slurry as depicted in Fig. 4. Chemical resistance is improved compared to conventional slurry walls or grout curtains. Barrier effectiveness can be monitored from between the double layer of liner. This is a significant advantage since most barrier walls are installed through contaminant plumes and contamination exists on both sides of the barrier making it difficult to tell if the barrier is leaking.

Another route to barrier wall construction using geomembranes is that taken by Gundle Lining Construction Corporation at Quincy, Illinois in the winter of 1986. The problem in this case was that a river was eating into a landfill; as a result, stream bank stabilization and protection of the hazardous wastes from stream inflow were required. Fig. 5 is a picture of the approach used.

A metal framed bin wall was lined with HDPE sheet on the side facing the landfill. Free-draining soil was used as internal backfill inside the retaining wall. Granular backfill for leachate collection was placed outside the wall adjacent to the HDPE. Fig. 6 is a picture of the completed bin wall. This type of construction could be modified easily for use in Superfund cleanup projects.

CONCLUSION

Containment of hazardous chemicals on the earth's surface is and will continue to be necessary for some time to come.

For long-term quality in barrier technology, attention must be paid to the barrier materials. Even apparently similar materials can behave quite differently.

The suitability of high quality geomembranes as barriers in the containment of hazardous waste has been and is continuing to be demonstrated on a very wide scale. The adaptability of the products and construction techniques to many different situations is continuing to prove their usefulness and is extending their application to the highly important work of the Superfund.

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A Construction Quality Control Program For Sludge Stabilization/Solidification Operations

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ABSTRACT

A construction quality control (QC) program was developed to monitor full-scale sludge stabilization/solidification operations often implemented during remedial and/or final closure activities at surface impoundment, storage pile and landfill disposal units. The QC program presented consists of monitoring the performance of a stabilization/solidification process involving the addition of a proportioned admixture (portland cement, cement kiln dust, fly ash, lime, soil or combinations thereof) to the sludges, thereby reducing sludge moisture content and enhancing structural stability of the waste material.

The QC program has been effectively implemented at several major surface impoundment closures and remedial action sites by utilizing a combination of technically recognized field construction and geotechnical-testing methods adapted to determine index properties, establish QC-criteria and provide reproducible data. An overview of stabilization/solidification operations is followed by a technical amplification of each principal element of the construction QC program.

INTRODUCTION

The stabilization/solidification of hazardous and non-hazardous sludges, contaminated soils and sediments often is determined from feasibility and value engineering studies to be a costeffective technology designed to improve physical and chemical properties of waste materials, thereby enabling more effective waste handling, containment, storage and disposal. Stabilization/solidification has been technically recognized by state and Federal regulatory agencies and throughout the industry as a viable hazardous waste management technology for certain wastes when utilized as a preliminary process for land disposal and land containment. Applications of the process include:

- Industrial pretreatment and on-site waste processing operations
 Final dewatering/moisture reduction process at treatment,
- storage and disposal facilities (TSDFs)
- Remedial action technology or pretreatment process for final stabilization/solidification of waste materials during closure of waste pits, surface impoundments, landfills and storage piles

The effectiveness of the technology depends primarily on the ability of a proportioned waste admixture to provide solidifying-stabilizing effects through improvements in physical and chemical properties of the waste. The mechanisms which produce these improvements are waste and admixture specific; however, they usually are limited to sorption and/or hydration through pozzolanic reactions. Characteristic improvements are mainly in the form of moisture reduction, change in particle distribution and subsequent improved physical consistency and load bearing capacity. Following a curing period, the resultant waste product usually has a physical consistency representative of a solid, dry mass more suitable for long-term containment in engineered land disposal systems.

The stabilization/solidification process depends upon a number of significant design parameters, engineering and operational considerations including:

- Determination of initial physical and chemical waste characterization
- Development of waste-specific admixture designs
- Methods of implementing full-scale stabilization/solidification operations
- Physical and chemical characteristics of the stabilized/solidified waste materials
- Economics of the technology relative to other available technology alternatives

Variations during full-scale implementation in any one or more of these design/engineering parameters can result in reduced overall effectiveness of the stabilization/solidification technology. The resultant stabilized/solidified waste material may be characteristically less suitable for long-term containment and thus create increased stress on the performance of the engineered land containment/disposal system.

This potential occurrence, combined with increased utilization of the technology and intensified emphasis now being placed on quality control/quality assurance mechanisms, necessitates development of a quality control (QC) program as an integral part of the design and construction management tasks associated with stabilization/solidification operations.

The purpose of this paper is to introduce a QC program developed from recognized construction management techniques and from standardized soils and concrete test methods adapted specifically to monitor full-scale waste stabilization/solidification operations.

The QC program draws on the experiences of developing wastespecific admixture designs and monitoring the performance of both full-scale batch process and in situ stabilization/solidification operations implemented during closure of sludge-storing surface impoundment units. Variations in the QC techniques presented herein are dependent on the project scale, site-specific conditions, implementation techniques and objectives of the technology application. The QC mechanisms should interest facility owners and operators, resident engineers and inspectors, contractors and regulatory personnel.

STABILIZATION/SOLIDIFICATION PROCESS OVERVIEW

The compound term stabilization/solidification, as used here-

in, refers to waste treatment processes which are designed to accomplish one or more of the following objectives:

- Improve handling and physical characteristics of the waste
- Decrease the surface area across which transfer or loss of contained pollutants can occur
- Limit the solubility of or detoxify hazardous constituents contained in the wastes'

Stabilization refers to the chemical interaction which may take place within the process to render the waste material less hazardous by converting contaminants to a less soluble and less mobile, toxic form. Stabilization alone may not result in improved or changed physical characteristics of the waste. Solidification does not necessarily result in a chemical interaction which detoxifies the waste material to any degree; however, it refers to the physical characteristic improvements which take place through addition of the waste admixture. Solidification accomplishes one or more of the above objectives by mechanically binding, fixating or encapsulating waste constituents into a monolithic solid with greater structural integrity.

Stabilization/Solidification Techniques

Current methods used to achieve stabilization/solidification of waste sludges, slurries, sediments and soils include:

- Absorption/adsorption
- Cement-based pozzolanic processes
- Lime-fly ash pozzolanic processes
- Encapsulation (micro and macro)

Each of these methods may be implemented as a single process or in combination with physical/chemical pretreatment systems such as dewatering, waste blending, neutralization, oxidation/reduction and chemical destruction.

Absorption/adsorption techniques mainly involve the addition of a dry, solid, fine-grained material (soil, ash, kiln dust or synthetic sorbents) to semi-solid and liquid wastes to reduce free liquids and improve materials handling characteristics.

Cement-based pozzolanic processes utilize the properties of portland cement and cement production by-products (cement kiln dust) to achieve the stabilization/solidification objective. The high pH of cement-based waste admixtures provides stabilization for many metal-bearing waste types by converting soluble cations to low solubility hydroxides or carbonates. Additionally, cementitious reactions produce a stiff to hard material consistency which incorporates contaminants into a hardened material matrix.

Lime-fly ash pozzolanic processes utilize the same principles as cement-based admixtures to achieve stabilization/solidification of waste materials. Pozzolanic reactions take place between lime, fine-grained siliceous materials and water to produce a hardened waste/admixture mass. As a result of its characteristically high pH, lime also reduces solubility and toxicity of certain waste constituents.

Micro- and macro-encapsulation techniques are less widely used to accomplish solidification/stabilization due to high cost and the need for specialized equipment and trained personnel. In general, these methods involve isolating wastes within a jacket of synthetic plastics or asphalt. The QC methods presented herein deal primarily with the more widely used pozzolanic processes of stabilization/solidification.

Process Implementation Mechanisms

Stabilization/solidification techniques are typically implemented utilizing in-place or batch processing methods to incorporate the admixture into the waste material. Generally, in-place or in situ methods involve mechanical introduction of the waste additive within the confines of a diked surface impoundment or constructed mixing area. The waste/admixture combination then is mixed in-place with earthmoving equipment (hydraulic backhoe, dragline, clamshell or bulldozer). The mixed material is left to cure prior to excavation and disposal, or the material may be disposed in-place and capped with an engineered cover system.

Larger scale stabilization/solidification projects may use a batch plant to obtain a homogeneous mix of waste and admixture. This technique typically involves application of conventional (or slightly modified) cement mixing equipment or pug mill operations. In this manner, the mixed materials normally are discharged to a curing area prior to final handling and disposal.

Several proprietary methods and mechanisms are marketed to implement the stabilization/solidification process. In most cases, however, these are only moderate variations to the generalized methods previously described and may serve to more economically or efficiently accomplish the mixing task.

STABILIZATION/SOLIDIFICATION CONSTRUCTION QUALITY CONTROL

Principal elements of a comprehensive construction QC program to monitor sludge stabilization/solidification operations include:

- · Obtaining chemical and physical waste characterization data
- Performing bench/field pilot-scale testing
- Evaluating QC data relative to the objectives or specifications of the technology applied

These QC elements are specified to: provide initial waste characteristics (index properties) of the unstabilized/unsolidified material; verify or finalize the waste-specific admixture design through bench and field pilot-scale operations; monitor full-scale operations for QC through inspection of equipment and operational processes, providing field documentation and record keeping; conduct a combination of field and laboratory physical tests to monitor changes in material index properties. Data generated by the QC program are evaluated in the field relative to project-specific standards and work is accepted or rejected for failure to meet the specified design.

The overall QC program is applied more rigorously to the in situ or area-mix methods of stabilization/solidification often implemented during closure of surface impoundments and unstable landfill or storage pile areas. Several elements of the program also can be effectively utilized to monitor QC during batch processing operations.

Chemical/Physical Waste

Characterization

Obtaining chemical and physical waste characterization data is a preliminary step in developing the QC program. Chemical characteristics of the wastes are essential to determine personnel safety considerations during handling, inspection and testing of processed and unprocessed wastes. Additionally, chemical composition of wastes may be utilized to determined the presence of chemicals which may interfere with the effectiveness of stabilization/solidification.

Chemical characterization both before and after stabilization/ solidification also is utilized to provide significant information on improved leachability and toxicity characteristics of the waste materials. Obtaining new chemical characterization data, however, is not essential to implementing the QC program since changes in physical characteristics of the wastes are utilized as primary indicators of the applied technology's performance.

This paper, however, is not intended to address associated improvements in chemical characteristics as a result of the stabilization/solidification process, as these occurrences are primarily waste-specific. On this subject, the reader is referred to appropriate references cited at the end of this article.

Physical characterization of wastes includes determination of density, moisture content, solids content, Atterberg Limits and compressive strength. These physical parameters define initial index properties of the unstabilized/unsolidified waste materials. Utilizing these indices (adopted from their traditional use in geotechnical and foundation engineering practice), a QC monitoring program is designed to define reproducible changes in material index properties and thus provide a criterion for field monitoring stabilization/solidification operations. The task of physical characterization may be conducted during bench-scale stabilization/solidification activities or as a preliminary field or offsite laboratory activity. The following subsections provide general definitions of the index properties utilized to monitor sludge stabilization/solidification operations.

Density

The density of a material may be expressed in terms of a wet unit weight or a dry unit weight. The wet unit weight includes the weight of porewaters, free liquids and particle solids in a given volume of waste and is utilized in the field and laboratory to establish informative weight-volume relationships of the material. The most significant use of this property is to determine accurate waste/admixture proportioning which is essential to maintain mixture quality control.

Moisture Control

By definition, moisture content is the ratio of the weight of water in a volume of waste to the weight of solids which usually is expressed as a percentage. Monitoring changes in the moisture content of the wastes provides a primary indication of the effectiveness of the stabilization/solidification process. Improvements in physical consistency, bearing capacity and stability of the waste normally are contingent upon a substantial reduction in moisture content.

Solids Content

Solids content may be utilized as an indicator of significant changes in waste composition. This index property often is used to determine changes in physical waste composition during areamixing or in situ methods of stabilization/solidification. From a QC viewpoint, changes in this value may serve to induce operational changes in waste/admixture proportioning to accommodate for a decrease in the solids content of the waste and achieve solidification.

Atterberg Limits

Atterberg Limits are utilized to establish criteria to determine and define various states of cohesive materials consistency relative to moisture content. Atterberg Limits are defined as the liquid limit (LL), the plastic limit (PL) and the plasticity index (PI) under ASTM designation D4318.

The liquid limit is taken as the moisture content at which a soil (in this case, waste) can be rolled into a 1/8-in. diameter thread before crumbling. The plasticity index is the numerical difference of the liquid and plastic limits and indicates the range of moisture contents through which the material remains plastic. Although these limits values have little direct meaning, correlations have been established to relate these index properties to other meaningful engineering index properties. The QC program for sludge stabilization/solidification operations utilizes Atterberg Limits, in combination with other index properties, as a mechanism to provide reproducible QC data.

Compressive Strength

Compressive strength (shear strength) is a measure of a ma-

terial's ability to withstand a load without causing overstressing or shear failure. There are a number of technically accepted field and laboratory test methods to determine compressive strength. In terms of its applicability to the solidification process, compressive strength can provide an accurate indicator of resultant changes in a waste material's physical consistency. Measured numerical values for compressive strength of stabilized/solidified wastes are correlated to various physical states of soil, concrete and rock in evaluating the effectiveness of the solidification operation. Values for compressive strength typically are expressed as an applied load per unit of surface area.

Table 1 summarizes the physical characterization tests and lists technically accepted testing protocols to determine each of these properties.

Bench/Field Pilot Scale Testing

Utilization of bench and/or field pilot-scale studies can pose significant advantages to refining the overall system design, including the construction QC program. Bench-scale test mixtures can be utilized to verify or supplement the waste/admixture design, providing both visual and numerical observations in establishing QC criteria. Determining the physical index properties before and after bench-scale stabilization/solidification can provide an idealized range of potential changes in measurable index properties, curing times and associated physical consistencies prior to full-scale or pilot-scale operations.

In the field, piloe-scale operations reduce uncertainties and refine the process of implementing full-scale stabilization/solidification operations. Further waste-specific characteristics and admixture properties often are discovered during this activity, and corresponding operational modifications (such as equipment requirements, material handling methods and construction sequencing) can be resolved. Pilot-scale studies also can be an effective mechanism for full-scale quality control. Mixture ratios may be altered due to previously unforeseen variabilities in waste uniformity, moisture content, admixture properties, stratified density or materials handling and equipment capabilities. Significant experience also can be gained by equipment operators and QC inspectors, in recognizing visual and textural changes in waste characteristics at various curing intervals of the stabilization/ solidification technique.

Table 1

Index Property:	Test Methods:
Density	ASTM D2937
	ASTM D2922
Moisture Content	ASTM D2216
	ASTM D3017
	AASHTO T217
	Pan Drying Method
Solids Content	U.S. EPA Standard Method for Settleable
	Matter (Storet No. 5008G)
Atterberg Limits	ASTM D4318
Compressive Strength	ASTM D2166
	Pocket Penetrometer
	Cone Penetrometer

Construction Oversight/Inspection

Construction oversight and inspection is an integral part of the QC program for full scale stabilization/solidification operations. Typical construction inspection techniques utilized to accomplish this task include:

- Visually observing mixing methods
- Monitoring waste/admixture ratios
- Documenting curing intervals
- Delineating curing areas
- · Determining material sampling and testing frequencies
- Establishing directives to implement corrective measures in the event of non-compliance with specifications

These QC tasks are conducted in addition to the field and laboratory testing program detailed in the following subsections.

Field/Laboratory Testing Program

A field and laboratory testing program is utilized, in addition to a planned system of construction inspection, to provide readily implementable tests to determine changes in initial index properties brought about by the stabilization/solidification process. Values for index properties derived from these tests then are evaluated against acceptable ranges or design standards established during bench and pilot-scale studies. In this manner, less rigorous and more frequent field tests for significant index properties can be conducted and values used as indicators that the process is achieving specified design criteria. Adherence to design criteria then is verified on a periodic basis through supplemental laboratory testing for design parameters (i.e., compressive strength, free liquids determinations, moisture-density relations, permeability).

Field Test Methods

Field testing methods utilized to determine initial index properties of unmixed sludges and monitoring changes in index properties of stabilized/solidified sludges include moisture content determinations, density measurements and in situ compressive strengths. Periodic moisture content determinations are taken on both mixed and unmixed sludges to monitor variations in moisture content caused by changes in waste uniformity and induced by hydration during the curing process. Methods of determining moisture content may include oven drying (ASTM 2216) or pan drying.

Atterberg Limits of stabilized/solidified materials should be determined at various intervals utilizing ASTM Method D4318. This index property then can be utilized to provide correlations between moisture content, curing intervals and physical consistency.

Field density measurements may be conducted utilizing the drive cylinder method to determine in-place density (ASTM Method D2937). This value should be utilized in checking mixture ratios and in evaluating density relative to optimum moisture-density relations of the material.

Several field methods are available to determine initial strengths and monitoring improvements in compressive strength of mixed and unmixed waste materials. Pocket penetrometer and cone penetrometer testing are utilized most often to provide a rapid field estimate of compressive strength and as a secondary verification of results obtained by laboratory unconfined compressive strength testing (ASTM D2166). The QC inspector should correlate field-determined moisture content, physical consistency and estimated compressive strengths at various curing intervals with laboratory-determined design parameters to provide a timely indication of acceptable or unacceptable work relative to project standards.

Laboratory Test Methods

A laboratory testing program can be utilized in conjunction with field testing methods to determine conformance with design standards and specifications. This program may be implemented utilizing an on-site geotechnical laboratory equipped to conduct physical parameters and an off-site analytical lab to analyze chemical parameters.

Laboratory-tested design parameters for QC determinations during stabilization/solidification operations may include:

- Unconfined compressive strength
- · Permeability of compacted, solidified wastes
- Toxicity testing
- Free liquids determinations
- Moisture-density testing

Unconfined compressive strength testing (ASTM D2166) is optimally performed on 3-in. diameter by 6-in. length cylindrical corings and remolded samples. Depending on the consistency of the waste mixture, corings can be taken by the drive cylinder method or by remolding freshly mixed materials into test cylinders. Remolded samples should be taken only in those mixtures where the material consistency is at or near the liquid limit as determined by testing or visual observations. In this instance, samples can be molded into 3 in. by 6 in. cylinders, left to cure for the specified design period and then extruded and tested for unconfined compressive strength. This testing may be conducted for a given mixture at various curing intervals to determine improvements in strength with curing time (i.e., 7, 14 and 28 days).

Project-specific requirements may necessitate determining waste permeability as a design parameter to evaluate the stabilization/solidification process. This measurement can be made by subjecting similar cylindrically molded samples or corings to falling or constant head permeability testing (ASTM D2434 or Corps of Engineers Manual EM 1110-2-1906).

Toxicity testing can be used to determine changes in certain chemical characteristics of stabilized/solidified waste through the Extraction Procedure toxicity test or the Uniform Leach Procedure.

Free liquid content of stabilized/solidified wastes can be tested using the U.S. EPA-specified paint filter test method. This determination has become increasingly important with recent landfill liquid prohibitions under RCRA.

Moisture-density (Proctor Testing) is a soils test method to determine relations between moisture content and various degrees of density based on compactive effort. This testing is used to a significant extent to monitor the placement of layered and compacted fills. ASTM Method D1557 is appropriate for conducting this test.

QC Data Evaluation

Evaluation of QC data consists of:

- Interpreting changes in index properties and visual characteristics of the waste materials during implementation
- Correlating these indices with design standards established during bench and/or pilot-scale testing
- Directing corrective measures in a timely and economic manner when index property tests are below expected values
- Accepting or rejecting work based on design parameter testing and the objectives of the technology application

CONCLUSION

Stabilization/solidification techniques often are implemented to improve chemical/physical waste characteristics prior to final handling and disposal and to mitigate waste constituent releases during remedial actions. The effectiveness of the technology application depends upon a number of design and operational parameters: (1) the ability of a waste admixture to react with the wastes to accomplish stabilization/solidification and (2) a mechanism to physically incorporate the admixture into the waste material safely, economically and efficiently.

A number of QC methods can be utilized to monitor the

stabilization/solidification process and thereby ensure, with reasonable certainty, that the objectives of the technology application have been satisfied. Combinations of construction oversight/inspection techniques, bench/pilot-scale studies and physical/chemical test methods have been introduced as mechanisms to implement a comprehensive QC program during stabilization/solidification operations.

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Considerations in Data Collection For Evaluation of Source Control Alternatives At Hazardous Waste Landfills

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ABSTRACT

To design and construct effective leachate source control alternatives, one must determine the internal structure and moisture conditions within a landfill. Test pits yield an excellent understanding of the structure of landfilled materials. Samples collected from test pits allow a reasonable degree of certainty that the material tested is representative of subsurface conditions.

In situations where waste is greater than 20 ft thick or where leachate head wells will be installed, drilling and sampling in refuse are routinely performed. Geophysical logging of boreholes or leachate head wells can yield substantial data on the internal structure of a site. The construction of leachate head wells can effect the leachate level observed in a well. Observed leachate quality can vary significantly with location and time. Data generated through these investigations are useful in assessing the effectiveness of various remedial alternatives.

INTRODUCTION

With the increasing number of landfill facilities being placed on the National Priorities List, investigating landfills for evaluation of source control measures is becoming increasingly important. Reducing leachate (free liquid) production rates and collection of leachate before release into the surrounding environment are important parts of remedial actions undertaken to mitigate releases from controlled or uncontrolled hazardous waste facilities. Conditions at each landfill are unique and require detailed site-specific investigations into their structure and the character of the wastes and liquids contained within them. Factors which can effect the selection and performance of source control measures at a landfill include:

- Presence and composition of daily and intermediate cover layers
- Refuse moisture content
- Presence of perched leachate zones at intermediate cover/ refuse interfaces
- Chemical character of the leachate, including the potential for multiphased leachate
- Leachate head levels
- · Refuse permeability and porosity
- Homogeneity of waste, particularly presence of containerized wastes or areas of special waste disposal
- Liner construction and composition
- Presence of granular material directly above the liner

Landfills are dynamic systems which can take up to 30 yr after filling is completed' to reach an equilibrium where infiltration through the cover equals leachate exfiltration. Exfiltration can occur by removal of leachate through the collection system or by leakage out of the base and sides of the landfill. Detailed investigations of landfill interiors are necessary to properly design remedial measures. If it is not recognized that moisture inflow is exceeding current exfiltration rates, measures to contain, collect or treat leachate releases may be undersigned. A treatment system's hydraulic or contaminant loads may be significantly increased when the refuse reached "field capacity" (maximum moisture-holding capacity) when average moisture inflow is passed through the unsaturated zone to become leachate.

During the past 15 yr, Warzyn Engineering has performed over 100 investigations at municipal, industrial and hazardous waste landfills. Many of the investigations have involved evaluating and monitoring leachate within waste materials in landfills. Some of the methods and procedures for investigating landfills, developed during the performance of these studies, are presented here. Examples from several sites are used to illustrate investigative problems and the effects data collection methodology can have on designing source control remedial measures.

INVESTIGATIVE APPROACH

Investigating contaminant releases attributable to a landfill requires documentation of conditions within the disposal area. The appropriate approach to investigating landfill conditions is dictated by the physical configuration and setting of the landfill and the known types of waste materials accepted. Depending on site conditions, some or all of the following activities are involved in a landfill characterization study:

- Test Pits
- Refuse Drilling
- · Leachate Head Well Installation
- Chemical and Physical Characterization of Wastes (from test pits or borings)
- Geophysical Logging of Leachate Head Wells or Refuse Borings
- Leachate Head Level Monitoring
- Leachate Analyses

A detailed discussion of the methods used to safely investigate the interior structure of landfills is presented below.

TEST PITS

Excavations into waste materials produce a cross-section of disposal activities. Test pits give a more representative view of the landfill structure than can be obtained from samples and cuttings from borings. The wider cross-section exposed and the larger amounts of material available for sampling can give site investigators greater confidence that the samples being collected and analyzed are reflective of the overall composition of subsurface materials. Test pits generally are excavated with a backhoe, which usually limits the depth of investigation to 20 ft. Backhoes with custom-built arms or draglines can be used to excavate below 20 ft, but hourly equipment costs increase substantially.

Prior to excavating the pits, a bulldozer can remove and segregate cover materials. This material can be used later as a cap when the pit is backfilled. By placing wastes on stripped areas, inadvertent contamination of surface materials is avoided. Attempts to place excavated wastes on polyethylene sheeting have been awkward and ineffective in containing potential contaminants.

Bulldozers or end-loaders are considerably more efficient in backfilling excavations than backhoes and substantially reduce investigation time. If the possibility for release of airborne contaminants exists, it is imperative that equipment be present to immediately fill the excavations if monitoring indicates that unacceptable releases are occurring.

At sites where drummed waste burial is suspected, an experienced backhoe operator may detect and remove drums intact. When investigating suspected drum burial areas, overpacks for containing ruptured drums and a small pump and/or adsorbent for recovering releases should be immediately available.

Before initiating subsurface work, all parties concerned should agree to the protocols and procedures to be used when drummed wastes are encountered. Generally, recovery of drummed wastes is not the primary goal of subsurface investigations. Once containerized waste is encountered during an investigative phase of a project, it is advisable to define the extent of drum disposal areas while minimizing drum contact and time spent on removal. If large numbers of drums are present, recovery usually is limited to those drums whose integrity have been compromised by the investigation. Large scale drum removal and containment is handled best by qualified removal contractors as an emergency removal or as part of site remediation activities.

Fig. 1 shows the location of test pits used to define subsurface features at a landfill facility in southeastern Michigan. The site was originally operated as an oil recovery facility, but the operation was closed after polluting local groundwater. Two oil ponds



Figure 1 Test Pit Investigation Program Investigation of Oil Pond and Drum Disposal Areas within a Landfill

and a number of drum disposal areas subsequently were covered with up to 20 ft of municipal refuse. Oil from the ponds was discharging into small ponds downgradient of the site. Definition of the ponds' locations and characterization of the materials associated with them was part of the Remedial Investigation of the site.

Based upon approximate locations obtained from aerial photographs taken when the site was active, 34 test pits were excavated to locate the oil ponds and drum disposal areas and to generally characterize refuse disposal at the site. Samples of sludge from the bottom of the oil ponds and underlying contaminated soils were collected for chemical characterization. Results from the test pit program were used to design a network of monitoring wells on and around the landfill to determine the extent of contamination from the oil ponds and the drum disposal areas. Data collected during the test pit program will be used to evaluate removal and containment alternatives during the Feasibility Study.

REFUSE DRILLING

When refuse depths extend beyond the limit of available excavating equipment of where leachate head wells are required, drilling in refuse is necessary to characterize the internal structure of a landfill.

Methods

Typically, a truck-mounted rotary drill rig similar to those used for groundwater monitoring well installation is used for refuse drilling. The drilling contractor should supply a machine with adequate power to perform the required drilling (minimum CME-55 or equivalent). Air rotary equipment should be avoided for refuse drilling because it enhances the rapid release of airborne contaminants.

Hollow flight augers are an effective drilling method in refuse. They have the following advantages over wash boring methods:

- A continuous casing is provided to isolate zones of perched liquids, without the time delays and expense of driving flush joint casings
- Water does not necessarily have to be introduced into the borehole. Clean water may be introduced if air monitoring indicates potential health and safety concerns exist from venting landfill gases up the augers. However, dry drilling makes determining the leachate levels easier.
- A continuous return of cuttings up the outside of the augers allows for more accurate logging of the borehole between samples.

When drilling in refuse, impenetrable zones may be encountered, due to objects as diverse as bedsprings, refrigerators or wood. Up to 25% of drilling footage in refuse is terminated due to penetration problems, so estimated drilling footages should be adjusted to reflect "false starts." If sufficiently highpowered drilling equipment is provided, it is generally more costeffective to choose a lesser footage rate on all refuse drilling than to pay a higher rate only on borings reaching the desired depth.

Sampling

Chemical analyses of waste or refuse samples provide data to:

- Characterize materials for removal actions
- Assess the compatibility of waste materials with barrier or collection piping materials
- Assess long-term leaching and future releases
- Characterize source materials for endangerment assessments

The samples collected during drilling yield a relatively undisturbed portion of subsurface material for physical and chemical testing. Parameters typically of interest include Atterberg limits (fine grained soils), moisture content, grain size and permeability (shelby tube samples). All samples of fine-grained soils from immediately beneath wastes should be evaluated for degradation of the material (typically characterized by an increase in permeability) by an immiscible heavier than water phase of leachate.²

Collecting data on refuse moisture conditions is important to determine if leachate production in a landfill is at equilibrium. If refuse above the observed saturated level within a landfill is near field capacity, then most moisture infiltrating through the cover will become a free liquid and will not be bound up in waste materials. If waste materials are not at field capacity, a greater portion of liquids infiltrating the landfill will remain as a free liquid as the waste nears field capacity. With increased amounts of leachate production, leachate head levels will increase and/or leakage rates will increase. The difference in currently observed versus projected leachate levels can significantly impact the design of leachate collection, holding and treatment systems.

Collection of split spoon (ASTM D-1586)' or shelby tube (ASTM D-1587)' samples during drilling operations can add valuable information on daily soil cover and liner conditions. Standard protocol' calls for collection of samples at 5-ft intervals; however, 5-ft sampling intervals may miss intermediate or daily cover materials that are causing perched liquids.

When the exact configuration of cover layers is required, either continuous sampling or sampling at 5-ft intervals and geophysical logging should be used. If a good correlation between geophysical logging and sampling observations is obtained and samples are not needed for physical or chemical testing, sampling many refuse borings can be eliminated. When it is suspected that a clay barrier is present beneath the waste or samples of the waste/native soil interface are desired, continuous sampling should occur over the last 5 to 10 ft of the boring. The exact depth is dependent upon the investigator's confidence in available data on the depth to the bottom of waste. The risk of liner penetration should be kept in mind during sampling. Compromising the integrity of a liner can subject the consultant to liability suits brought by the site owner or third parties.

Geophysical Logging

Geophysical logging can be used to obtain additional data on the subsurface structure and moisture conditions within landfills. Below is a brief description of the logging which typically is performed on refuse borings:

- Natural Gamma Logging—will differentiate between clay rich (daily and intermediate cover) and clay poor materials (refuse); gamma logging may be inappropriate if sand or sandy silt was used for cover; however, determination of cover configuration is less important for coarser materials, since they are less likely to impede liquid flow.
- Gamma-Gamma Logging—indicates changes in bulk densities of materials; cover materials typically have a higher density than the surrounding refuse.
- Neutron Logging—will indicate moisture content; the probe is sensitive to the hydrogen content of organic materials.

Refuse boreholes typically are logged with several methods to confirm observations. Geophysical logging can be performed in an open borehole before a well is installed or down a leachate head well. However, the density of the steel and the hydrocarbon content of the PVC must be taken into account in log interpretation. Use of calibration test barrels is recommended on a site-by-site basis. Logging before well installation will avoid interpretation problems caused by well construction, such as "kicks" caused by casing collars. If open boreholes are to be logged, a commercial well logging firm should be employed with heavy-duty equipment for raising and lowering the probes. Without such heavy-duty equipment, probes may be lost if the borehole has partial cave-ins. In addition, NRC licensing requirements virtually demand use of subcontractors for radiation logging, due to experience requirements. Logging open boreholes can result in substantial standby charges for the waiting periods between drilling boreholes. It is not advisable, given the unstable nature of refuse, to keep all the boreholes open and have them logged at the end of drilling. If cased wells are logged, smaller portable logging units can be used to effectively log the boreholes.

Geophysical logging can substantially improve the understanding of the interior of a waste site. Fig. 2 presents geophysical logging results from a leachate head well at a landfill in southeastern Wisconsin. Adjacent to the three logs is the interpretation of conditions based on the logging. The well was constructed so the 5-ft screen was set and sealed at the bottom of the refuse. The liquid level observed in the head well was substantially below the level where geophysical logging indicated continuous saturated refuse started. All the leachate head wells were screened at the bottom of the site and consistently underestimated the saturated waste thickness.³

The logging also determined the cover and refuse sequencing. Throughout the site, clay materials proportionately increased at the bottom of borings due to consolidation of the refuse layer. Two zones of perched liquids also were defined.



Geophysical Logging Results

LEACHATE HEAD WELL INSTALLATION

Approach

Leachate head wells can be screened at different depths within a landfill. Prior to well installation, the investigators should have a clear understanding of the ramifications of the type of well construction used. Below is a summary of the three main types of installations and how their construction may affect data collected from the well. Diagrams of each type are shown in Fig. 3.

Wells Screened and Sealed at the Bottom of the Waste

Wells constructed in this fashion act as piezometers, with the leachate level noted representing the piezometric surface at the bottom of the landfill. The observed leachate levels can be considerably below the saturated refuse level, if saturated refuse is relatively thick and leakage is occurring out the bottom of the site. Analytical results of samples collected from a well sealed at the bottom of the refuse may be reflective of an immiscible heavier-than-water phase in the leachate. Leachate quality results should be considered only representative of the interval in which the well is screened, and not overall site leachate quality.

Wells Screened at the Bottom of the Waste

Wells constructed in such a manner with sand pack extending to near the observed saturated level will probably provide a representative measurement of the leachate head level within refuse. Care should be taken so the sand pack does not extend into the perched leachate pockets, possibly overstating leachate levels at the base of the site. Wells with saturated sand packs which extend considerably above the well screen may not detect any floating phase leachate. Wells with screens which extend over the entire saturated zone typically are not used due to the cost of the well screen.

Wells Screened at the Top of Saturated Zones

Wells situated near or at the top of saturated sequences are a good indicator of the saturated level of leachate within a landfill. If a well is installed in a perched saturated zone, care should be taken not to rupture the layer perching the liquids. When thick sequences of saturated refuse are present, a well screened at the top of refuse may be installed in conjunction with either of the two well types discussed above.



Figure 3 Leachate Head Well Construction

Fig. 4 presents an example of the sensitivity of observed leachate levels to the construction of the leachate head well. The hydrograph shows the leachate level in a leachate head well screened and sealed at the bottom of a large landfill used for codisposal of municipal and liquid wastes. A review of leachate levels for the well indicates over a 50-ft increase in observed leachate head levels between July and December of 1984. The rapid rise in leachate head levels corresponds to a period when extensive filling was occurring near the well. The weight of the increased refuse and corresponding pore pressure at the bottom of the site accounts for the increase in head level pressure without an increase in leachate volume.³ This also indicates that the leachate was effectively confined at the base of the site by the overlaying refuse and clay cover layers. Other leachate head wells in the area also showed an increase in leachate head levels.



Leachate Head Level Changes Over Time

Construction

An important consideration in constructing leachate head wells is the stress put on the wells by settling refuse. PVC wells typically bend or shear, limiting the useful lifetime of the wells. Galvanized steel casing often is used. Although settlement in a deep fill may eventually constrict the effective diameter of a steel well, the well should remain intact to prevent an open conduit to the bottom of the site.

Bentonite grout is preferred over cement grout when constructing seals in leachate head wells. Because bentonite remains plastic after placement, it retains some ability to adjust as refuse settlement occurs. Cement grout, which eventually sets up, will crack as displacement occurs, increasing the probability that seepage will occur along the seal.

The use of galvanized steel well riser pipe and well screens can create a problem with leachate quality sampling. Leachate typically has a low pH, which may allow zinc and other metals to leach over time. If the leachate head well is in a low permeability zone, it may be impossible to collect samples that are not tainted with zinc and other trace metal impurities such as cadmium and arsenic from the galvanized steel pipe. If those compounds are a major concern, it may be advisable to use stainless steel well screens and bail the well dry before sampling, so liquid with a minimum contact with the riser pipe is collected.

Selecting the proper sized sand packs around leachate head well screens can be a problem. The variable nature of most refuse makes selection of a particle size for backfilling around screens speculative at best. A fine sand (0.1 mm) acts as a filtering mechanism to reduce the amount of fine suspended materials (often fine black particles of decaying refuse) which enter the well screen. Since leachate samples generally are analyzed on a total basis (not filtered), particulate matter in a sample can significantly affect leachate quality results. The use of a fine grained sand pack limits the use of the leachate head wells for horizontal permeability testing. In high permeability zones, the maximum permeability detected may be limited by the permeability of the well screen filter.

The screen pack's grain size should be determined by the intended use of the well and not necessarily by the suspected particle size of the surrounding materials. When leachate head wells will be used for permeability and leachate quality testing, a coarse sand (0.7 mm) has been a good compromise.

Distribution of Wells

The vertical and horizontal distribution of leachate head wells is ultimately determined by the investigator's confidence in the homogeneity of the site. It is advisable that each distinct phase or area of a site be instrumented with leachate head wells. At a minimum, on a site where no detailed engineering plans are available and little or no data are available on the waste structure or leachate characteristics, one leachate head well should be installed for every 5 acres of fill area. The number of nested (multiple level) wells installed depends on the depth of saturated refuse. Where a saturated thickness of 20 ft above the top of the well screen is detected, it is advisable to install more than one well.

Table 1 contains average values of indicator parameters from leachate head wells installed in a 12-acre municipal landfill in northwestern Wisconsin. The head wells were installed at essentially random locations equidistant along the longitudinal axis of the site. The apparently anomalous analyses for head well number two (LH-2) were confirmed with subsequent analyses. Interviews with local citizens and previous site operators indicated that the well probably was located where open burning was conducted until the late 1960s. The area used for burning was bermed off from other sections of the site, allowing a pocket of unique quality leachate to form.

Table 1					
Average Leachate	Quality at a	Landfil) in	NW	Wisconsin	

Parameter	Well Designation				
	LH-1	LH-2	LH-3		
Conductivity	6338	260	4425		
Total Alkalinity	1638	47	1328		
Chemical Oxygen Demand					
(COD)	3048	51	2506		
Chloride	1293	43	856		
Total Hardness	1965	69	1593		
Dissolved Iron	122	0.005	35		

Results in mg/l except conductivity, which is in umhos/cm

Investigators need to consider the time frame of leachate sampling during a Remedial Investigation. Fig. 5 shows changes in indicator parameters for leachate from a collection manhole at a large engineered landfill in central Wisconsin. The variability in indicator parameters seen at this site and others implies that investigators need to seriously evaluate how representative their data are of long-term leachate quality. Potential variability in leachate quality must be factored into evaluations of leachate collection and treatment alternatives and subsequent designs.



Leachate Quality in a Landfill Collection System

CONCLUSIONS

- Test pits are a relatively inexpensive and effective method to investigate waste disposal areas where waste does not exceed 20 ft in thickness.
- Refuse drilling, when used in conjunction with standard sampling methods and/or geophysical logging, can provide a good indication of the internal structure of a landfill.
- The construction of leachate head wells can effect observed leachate levels. Leachate head wells can substantially underestimate the depth of saturated refuse.
- The location of leachate head wells and sampling time frame can impact the observed leachate quality.

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Fixation/Solidification of Hazardous Waste At Chemical Waste Management's Vickery, Ohio Facility

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ABSTRACT

Chemical Waste Management, Inc. is ceasing treatment of hazardous/toxic wastes in open surface impoundments at the Vickery, Ohio, Facility. The lagoons are being closed and wastes which are highly acidic are being neutralized and chemically fixed with dolomitic quicklime and cement kiln dust. This fixed material then will be placed in a secure landfill.

The paper describes the reagent selection and the procedures and methods used to solidify the toxic sludge which produced 250,000 yd of fixed material. The design of the landfill to hold the hazardous material also is described.

INTRODUCTION

The Chemical Waste Management site at Vickery, Ohio, is located six miles east of Fremont, Ohio, on State Route 412. The 248-acre site is bounded by the turnpike to the North, State Route 412 to the South, State Route 510 to the East, and County Road 244 to the West. Only about 97 acres are used for the waste disposal operations; the remaining land is farmed (Figure 1).



Figure 1 General View of Chemical Waste Management, Inc. Site, Vickery, Ohio, Showing Surface Impoundments to be Closed.

The Site originally was started by a local resident in 1964 for the purpose of oil recovery. In order to "crack" the oil emulsions, acid was required. For economic reasons, waste acid was used and this led to the construction of surface impoundments in 1970 to hold this material. From those early beginnings, the site developed. By 1971, five lagoons existed.

The first deep well permit was obtained in 1975, because disposal by evaporation was considered an unacceptable method of disposal by the authorities. Four deep wells had been permitted by the time Chemical Waste Management, Inc. purchased the site in 1978. Two further wells have been installed since that time.

In early 1983, PCBs (less than 500 ppm) and dioxins were found on-site in three of the surface impoundments. The Company, in negotiations with both the State of Ohio EPA and the U.S. EPA, decided to close all five surface impoundments that remained onsite. Because the controlling regulations for disposal would be the PCB regulations promulgated under TSCA, the available options permitted were limited to disposal in an approved landfill, incineration in a U.S. EPA-approved incinerator or disposal via some alternative methods approved by the U.S. EPA Regional Administrator. A risk assessment study was undertaken which showed that off-site disposal with the large volume of material and distance to an approved disposal site posed a greater risk than on-site disposal. It was, therefore, decided to develop a plan to stabilize and fix the material and dispose of it in an on-site closure cell, which would be acceptable to both the U.S. EPA and the Ohio Environmental Protection Agency (OEPA).

This proposal was further influenced by the natural soil condition of the area, which comprises a very low permeability clay. The area, which is rural, requires the installation of extensive land drainage systems by local farmers.

CLOSURE PLAN

The initial concept for closing the impoundments was fairly simple and straightforward. There was excess land on-site where a land cell could be constructed and site personnel had solidified pond sludges in the past utilizing a mixture of sugar beet tailings and lime kiln dust.

However, as discussions with the U.S. EPA developed, it became clear that a restriction on the closure cell was likely to be imposed. For a variety of reasons, the U.S. EPA required that any closure cell constructed at the site for the disposal of fixed material from the ponds should occupy the same location that initially was occupied by the three impoundments containing the PCBs.

Because of this, an additional restriction resulted: the volume of material the closure cell could hold was limited by the plan area of the three ponds and a restriction on the height to which the cell could be filled. Any reagents used for the fixation process would, therefore, have to keep "bulking" to a minimum.

SELECTION OF REAGENTS

Battelle-Columbus Laboratories were retained to evaluate a variety of solidification agents. Eight various combinations were used (Table 1), and evaluated on the basis of the Extraction Procedures toxicity test as described in the *Federal Register*, May 19, 1980; in addition priority pollutants PCBs, and 2, 3, 7, 8 tetrachlorodibenzo-p-dioxin (2, 3, 7, 8-TCDD) were measured. In addition to assessing the efficiency of fixation, "bulking" of the resultant fixed material also was assessed.

Samples of unfixed sludge and fixation materials were subjected to extraction and analysis for the contaminants mentioned above. using U.S. EPA protocols. For each system, the effectiveness of the stabilization alternatives were compared in what was the relative attenuation of the contaminants. Analyses of the samples were reviewed and compared.

None of the three contaminant compounds found in the pond sludges and deemed particularly important at the outset of the study, namely 2, 3, 7, 8, tetrachlorodibenzo-*p*-dioxin (dioxin), polychlorinated byphenyls (PCBs) and dichlorobenzidine (DCB) were detected in any of the leachates generated.

Table 1.

Composition of Sludge Fixation Alternatives (All Parts on a Weight Basis)

System 1

100 parts sludge 35 parts cement kiln dust 40 parts sugar beet tailings 15 parts steel pickle liquor

System II

100 parts sludge20 parts cement kiln dust60 parts clean site clay

System III

100 parts sludge 20 parts cement kiln dust 30 parts fly ash 30 parts calcium sulfate sludge

System IV

1

00	parts	sludge			
30	parts	cement	kiln	dus	it
20	Darts	calcum	sulf	ate	sludge

System V

100 parts sludge 30 parts cement kiln dust 20 parts Portland cement

System VI

100 parts sludge 20 parts cement kiln dust 20 parts beet tailings 20 parts Portland cement

System VII

100 parts sludge 15 parts quickline (calcium oxide)

System VIII

100 parts sludge 15 parts quicklime 20 parts cement kiln dust

From a leachate quality standpoint, Fixation Systems I, II, VI, VII, and VIII generally produced very good and virtually equivalent results for the Vickery sludge [1]. System III leached significantly greater quantities of lead, while IV and V afforded the poorest performances of all the systems tested.

Volumetric tests on the various systems showed significant variations on fixation (Table 2).

With the restriction on volumetric capacity in the closure cell, clearly Systems VII and VIII had advantages over the other systems.

Another factor considered which influenced the final decision on system selection was the availability of reagent material. Sugar beet tailings which were utilized in System I and VI proved to have limited local supply and were very seasonal. This, in effect, eliminated these systems, while the bulking factor eliminated System II.

Material for Systems VII and VIII was then subjected to strength

Table 2. Waste Volume Increase for Fixed Sludges

System	Volume Increase %
1	56
11	47
111	47
IV	(Not Tested)
v	19
VI	26
VII	9
VIII	21

and consolidation tests [2]. These showed that with both samples there was a high initial compression and relatively low consolidation compression (Table 3).

Table 3.								
Volume	Changes	with	Single	Load	Increment	of	3600	lb/ft

Total Volume Decrease (#)	12.1	7.3
Volume Decrease Due To Initial		
Compression (%)	7.0	5.5
Fluid Drained (% of original weight)	5.9	0.8
Increase In Density (")	7.1	7.1

Both materials exhibited measurable secondary compression but only equated to a settlement of 2-4 in. over a period of approximately 100 yr on a 45-ft high cell.

Because of the lesser bulking of the calcium oxide, it was decided to utilize this mix, but add limited cement kiln dust to reduce consolidation and fluid leachate. A mixture of 100 parts sludge to 15 parts calcium oxide and 5 parts cement kiln dust was selected.

FIELD EVALUATION

Having approved the constituents for the reagents and accepted the results obtained in the laboratory for fixing the pond sludges, the U.S. EPA required proof of the results in a field trial.

At the site, a small pond (approximately 180 ft x 85 ft) containing some 2000 yd of sludge, was designated to be treated as a pilot project.

- This project was used to determine three things:
- Could the results obtained in the laboratory be reproduced in the field and would the fixed material have acceptable structural strength?
- How could the additives be applied to minimize dust generation?

Could the material be mixed satisfactorily with back-hoes?
 For the pilot project, super bags were filled from a silo with the



Figure 2 Storage Bins for Reagent Storage During Closure Operations with Dust Collectors in Position.

alcium oxide and cement kiln dust. The weight per bag varied from 000 to 3000 lb, and these were placed on the sludge using a crane $_{0}$ support the bag approximately 6 to 12 in. above the surface. The pilot project showed that this method of dispensing the reagent vas practical and that mixing with a back-hoe was possible and produced satisfactory results.

The pilot project took three weeks to complete working 12 μ/day . Based on the pilot project experience, it was decided that wo shifts should be worked on the main project.

SITE PREPARATION

Because the U.S. EPA required the closure cell to be located in the same area occupied by the ponds, a temporary stockpile area for the fixed material had to be constructed.

This requirement meant that significant construction work had to be completed prior to the commencement of any operation. The stockpile area, approximately 6 acres in size immediately east of the ponds, had to be prepared by lining the area with a minimum of 3 ft of clay and providing a retention area to contain precipitation run-off from the stockpile. The capacity of the retention area was to accommodate a 24-hr, 25-yr storm. Three quarters of a mile of fence line was erected to isolate the operational area from the rest of the site. Separate areas were established for personal and equipment decontamination, both having their own water supply and wastewater disposal systems.

Because of concerns about dust (the reagent material was of 16 mesh and below), a dust collection system was installed at the point of discharge to the storage pigs. Storage pigs (Figure 2) were employed to ensure that any failure of transportation or factory production could be accommodated for up to 3 days.

In addition, lighting was installed on the entire 12-acre site, impoundment and stockpile areas to provide background lighting for the night shift who utilized mobile lighting sets for point lighting (work area lighting).

It already has been mentioned that, during the pilot project, super bags were used. Because these bags sustained damage and often were not reusable, it was decided to manufacture reusable dispensers to dispense the anticipated 20,000 tons of reagent. Each dispenser could hold approximately 4,500 lbs, could be loaded pneumatically, had a dust control facility and could be unloaded mechanically and remotely. Because of the volume of reagent, eight dispensers were manufactured and used throughout the project.

Prior to startup, two further tasks had to be accomplished. The first was the installation of weigh scales to control the weight of reagent dispensed. The second was to train all personnel in the use of self-contained breathing apparatus and all aspects of the safety rules, regulations and operating procedures.

POND CLOSURE

The three ponds to be closed (Ponds 4, 5 and 7) were each 200 ft wide and 800 ft long. The ponds had been surveyed in 1983 in an attempt and estimate the depth of sludge. The best estimate that could be obtained indicated that the depths were likely to be 3 ft in Pond 7, 8 ft in Pond 5 and 14 ft in Pond 4. A portion of Pond 4 had also been closed previously; included in the Closure Plan was the re-opening, excavation and fixation of the material in the previously closed section.

Because it was not known what problems were likely to be encountered, it was decided the fixation/solidification process should take place in Pond 7 first as it contained the least amount of sludge.

The supply of reagent was contracted with three different suppliers. Two quick lime suppliers were used, as a single supplier could not supply the total volume necessary. Use of two suppliers also provided an alternate source in case of factory breakdown. Only one supplier was used for the cement kiln dust. The additives were delivered in bulk, using tankers which discharged their loads pneumatically into the eight storage pigs, each of which held between 100 and 150 tons. Six pigs were reserved for the calcium oxide and two for the cement kiln dust.

From the storage pigs, the reagent material was pumped

pneumatically into the reagent applicators. During this operation, the applicators were placed on scales so the reagent could be weighed as it was loaded. Weighing was necessary to determine and maintain the mixing rates in the pond.

The plan for the actual mixing operation utilized two cranes, each with a 100-ft boom. One crane sat on the East dike and one on the West dike to dispense the reagent. The cranes were rigged with double cables, one supporting the applicator and the second enabling the crane operator to activate the lever to operate the clam shell gate at the base of the unit and deposit the reagent.

As three back-hoes were used in the mixing operation, each crane served one and a half hoes. To simplify the reagent application, the applicators were numbered "1" through "8"; "1" through "6" were filled with quicklime and "7" and "8" with cement kiln dust. This mechanism maintained the 3:1 ratio for the fixation recipe. To make things even simpler, odd numbered applicators were used on the West dike and even numbered applicators on the East dike.

The applicators were pneumatically loaded while connected to both the pigs and a dust control system, which was located beside the scales. The weight of reagent in each applicator was recorded before the applicator was picked up and transferred by a forklift to the cranes. The cranes moved the applicators over the sludge and deposited the reagent, utilizing their second cables to control the quantity of material deposited (Figure 3). If the chemical



Figure 3 Crane Depositing Cement Kiln Dust on Sludge with Back-hoe on Right Mixing in Calcium Oxide.



Figure 4 Back-hoe Outloading Solidified/Stabilized Sludge onto Dump Truck.

reaction between the sludge and reagent became strong, the quantity of reagent deposited was reduced. The crane operator varied the quantity of reagent applied as required by the prevailing conditions in order to control heat and dust generation.

Once the reagent was deposited, the back-hoes started mixing with a "kneading" action. As soon as solidification started, the solid material was used to form a dike around the mixing area. Additional reagent then was placed in the mixing area and mixing continued until solidification and fixation were completed. Completion of fixation was determined using the following criteria:

- Visual inspection (the material to be solid and earth-like)
- No free liquid
- Possible to excavate with back-hoe (material sitting in bucket and not flowing over edge)
- Holding angle of repose of 30-45° when stockpiled
- Maintain a ratio of reagent/fixed material of 1/6 or 0.13-0.16

The material then was excavated and cast to the rear of the backhoes. The dike then was broken to permit an inflow of additional sludge. This process was repeated until sludge ceased to flow to the hoes. The back-hoes then moved out onto the fixed material using crane mats. This process was repeated until each pond was fixed.

Once the material had been fixed and cast behind the three mixing back-hoes, a fourth hoe on the dike loaded the materials into trucks (Figure 4) for transport to the stockpile area. As the back-hoes moved along the bottom of the pond, a bulldozer was used to feed the material to the fourth back-hoe which then loaded it onto trucks for disposal in the stockpile.

The sludges in all three ponds took just under 5 months to solidify and fix, utilized approximately 20,000 tons of reagent and produced about 170,000 yd³ of fixed material. Once all the sludges had been removed, the previously closed portion of Pond 4 was excavated material fixed where necessary and stockpiled. A further 70–80,000 yd³ of material were removed and 2,000 tons of reagent were used.

Once all the fixed material and the southern half of Pond 4 (i.e., the previously closed portion) had been excavated and stockpiled, there was a requirement to ensure the remaining clay was clean. This requirement was met by excavating at least 6 in. of clay and transporting it to the stockpile. Tests then were run on samples of soil, and excavation continued until the area was shown to be clean based on laboratory results. Depths of excavation varied by the time clean conditions were reached. These were generally between 6 and 18 in. but in one location reached 3 ft. The most difficult contaminants to remove were the heavy metals.

All the material excavated produced a stockpile approximately 46 ft high and measuring 620 ft x 460 ft (Figure 5). One plan requirement was that the pile should be covered. The initial con-



Figure 5 Stockpile (in upper picture) with Runoff Retention Area. Call Construction Starting (in foreground).

cept was to utilize gunnite but because of the size of the stockpile, a gunnite cover would have cracked extensively unless the cover had been constructed with significant thickness and included reinforcement. An asphalt cover also was considered. Finally, a polypropylene cover was selected and approved by the OEPA, but a restriction on the number of separate sheets utilized was imposed by the U.S. EPA. The restriction was eight sheets. A cover was placed on the stockpile using the required eight sheets, but these were lost in gale force winds of over 55 mi/hr. soon after installation. The cover has been redesigned utilizing 53 sheets—12 ft wide and of varying lengths. This construction has proved to be much more satisfactory and has been in place for the last year.

The stockpile retention area contains all the runoff from the stockpile and has a capacity of approximately 1.5 million gal. In order to dispose of the volume of liquid in the retention area, a pipeline was installed to discharge the liquid to the two remaining surface impoundments (Ponds 11 and 12).

SAFETY

Throughout the entire fixation process, safety was of the utmost importance. It already has been stated that a training course for personnel was held prior to the start of operations. In addition to instruction in the operation and use of breathing apparatus (Figure 6), instruction also was given on potential hazards, first



Figure 6 Workers Wearing Full Personnal Protective Equipment.

aid, safety equipment locations, both project and site contingency plans and last, but by no means least, dressing, undressing and decontamination procedures.

Apart from the personnel aspects of safety, both air monitoring and monitoring of decontamination procedures were undertaken extensively. With regard to air quality, three different aspects were monitored. These were:

- Perimeter monitoring; i.e., air at site boundary
- Organic vapor analyses monitoring within the operational area
- Monitoring of operational personnel

MONITORING

Perimeter Monitoring

Monitoring was undertaken to measure the air quality at the perimeter of the site and to see if there was any significant increase of contaminants in the air during mixing. In order to establish a base, air samples were taken prior to the commencement of any operation to measure the level of contamination existing in the air, to determine what those contaminants were and to establish background readings.

Further samples were taken over weekly periods during the fixing operations in Ponds 4, 5 and 7. The results showed that there was a slight increase in air contaminant levels during the fixation process. These levels were well below a level, of concern, but did show an increase as the fixation process went from Pond 7 to Pond 5 to Pond 4. This increase was expected and would seem to indicate that the fixation of the remaining ponds will produce even less air-borne constituents than already have been experienced.

OVA Monitoring

The level of protection employed by the workers was determined by monitoring at 16 discrete locations within the operational area with an Organic Vapor Analyzer (OVA). This device was read at each location prior to start-up. Throughout the entire operation, which lasted approximately 6 months, readings on the OVA were taken twice per shift, every shift. By reviewing these readings, the level of protection to be afforded the men was determined after consultation between the Project Manager and Safety Officer and Industrial Hygienist.

Personal Monitoring

Finally, to supplement all of the above data, personal monitoring devices were worn by 20% of the work force during each shift. These devices monitored 16 constituents and gave an indication of the level of contamination in the work area. These results, in turn, could be correlated with the OVA readings. The collection tubes were analyzed on-site with a 24 hr turnaround time.

CLOSURE CELL

The basic TSCA requirments for a toxic landfill are fairly straightforward. There should be a 50-ft separation between the cell and groundwater, and the material should be sealed from the surrounding area by a clay liner with a minimum thickness of 3 ft and a maximum permeability of 10^{-7} cm/sec.

The TSCA land cell designed for Vickery is much more sophisticated than the requirements require and has been evolved over the past 2 yrs after considerable discussion between the U.S. EPA and the Company and redesign by our geological consultants.

The geology of the site is good, as was demonstrated by the depth of soil contaminated in the surface impoundments. Remembering that the impounded material was highly acidic and was present in the impoundments for some 15 yrs, the penetration was minimal. Any form of liquid penetration in the same area is difficult. The area always has significant ponding of water, and farmers have to employ extensive land drainage schemes. The main aquifer is also between 50 to 600 ft below ground surface. It was because



Figure 7 Vickery Closure Cell—Double Liner Schematic

of this geology that there was the possibility of building the land cell on-site. However, it was stipulated that the disposal area should be accommodated within the area previously occupied by the ponds.

The first problem encountered with the cell design was to obtain the 50 ft differential between the groundwater and the cell base. Because the area is flat and virtually non-permeable, groundwater is at-grade. It was requested that a variance from the 50-ft separation from the aquifer be granted and a 2-ft thick gravel capillarity barrier be installed below the cell in order to prevent any upward migration of the groundwater. Water entering this capillarity barrier or drain would be collected and pumped to a holding tank. Liquid collected in the tank would be tested and either disposed of through the deepwell system or discharged into the surface water system, depending on its quality.

A variety of designs for the cell were submitted, and these have been reviewed over the last 2 yrs. The final design (Figure 7) is probably the most advanced for any form of land cell.

Immediately above the capillarity drain or barrier, compacted clay will be placed and shaped for the gradients for the ultimate leachate collection systems. The gradients to be installed, which will create collection points at the north and south edges of the cell, are significant, being in excess of 2%. Because the cell length is just under 800 ft, 8 ft of clay need to be placed at the center of the cell to provide satisfactory gradients.

Above this contoured clay will be a 2-ft clay liner. QA/QC for installation will have a much tighter specification than for the contour clay, and routine field testing will be conducted to ensure a permeability of less than 10^{-7} cm/sec.

Above the clay liner will be two 60 mil HDPE liners. Each liner will have its own leachate collection system and sump (Figures 8 and 9) together with pumps and ancillary equipment to extract any leachate that may collect. Filter fabric will be used on either side of the liners to protect them during installation.

QA/QC procedures on the liner system will be strict and conducted by an outside consulting firm. QA/QC control for the liner will not be restricted to the installation process only, but will include both manufacture, storage and transportation. During the installation of the liners, inspection and non-destruction testing will be conducted on 100% of all joints. In addition, one destructive test will be conducted for every 500 ft of joints. These destructive tests will be accomplished in the field and confirmed in the laboratory.

Once the closure cell design was formulated and the specifications for liner and filter fabric evolved, testing was undertaken by the Battelle Laboratories in Columbus, Ohio, to determine the compatibility of the materials with the possible leachate. In the testing process, tests were conducted under the most stringent conditions, utilizing actual pond sludge. The tests were done in accordance with U.S. EPA Method 9090 and at elevated temperatures. No deterioration of either the liner material or the filter fabric was observed, and the lifetime expectancy of both is in excess of 30 yr.

Once the cell has been built, the fixed material from the stockpile will be placed in the cell, but only to a height ensuring that the side slope gradients do not exceed 1 in 5. A cover will be placed over the cell to encapsulate the material completely.

The cover, like the liner, has been upgraded (Figure 10). A double liner will be placed above the material. There will be a compacted 2-ft thick clay liner, laid to the same tight specifications as the bottom clay liner, followed by a 40 mil HDPE synthetic liner. Once again, the liner will be protected by filter fabric. Above the liner, there will be a one foot sand drainage layer followed by 18 in. of compacted clay and top soil. The final cover will be seeded with grass, and the whole area will be fenced.

MONITORING WELLS

Once the Closure Cell has been constructed and covered, it will be marked and the whole area will be monitored for a minimum of 30 yr.

To this end, 39 monitoring wells have been installed around the



Figure 9 Secondary Leachate Collection System Details

site and a further six wells will be installed. These wells will monitor groundwater at various depths down to 165 ft. The distribution of wells will surround all the closed ponds, and test samples taken from these wells will be compared with samples from a number of up-gradient wells.

CONCLUSION

When the Closure Cell is completed, it will be a state-of-the-art landfill. Chemical Waste Management, Inc. is dedicated to developing and managing the most environmentally-sound disposal sites. The Company has demonstrated that, working in close cooperation with both the Federal and State regulatory agencies, any potential environmental problems can be solved in an efficient and practical manner.

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Figure 10 Vickery Closure Cell—Final Cover Schematic

Field Experiences with Silicate-Based Systems for the Treatment of Hazardous Wastes

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ABSTRACT

A new chemical treatment for hazardous waste applications has been developed and found successful in an actual field application. Soils generating leachable lead concentrations in the range of 200 to 300 mg/l using the California WET procedure (which is far more stringent than U.S. EPA's Extraction Procedure Toxicity test) were subjected to treatment and subsequently re-tested for lead. Test results show the leachable lead concentrations in the treated material were reduced to only 2 to 4 mg/l (the California standard is 5 mg/l). In one case, a sample having a concentration of 2,300 mg/l was reduced to 10 mg/l lead with only a modest increase in treatment. The cost of the treatment is in the range of \$15 to \$20 per ton. This chemical treatment is based on the use of a proprietary silicate-based system in combination with a cementitious fixative, such as lime, which generally does not result in substantial volume increases, as is typical with traditional fixation and stabilization approaches.

INTRODUCTION

Results obtained under field conditions of a new silicate-based treatment system for mitigating leachable heavy metals are presented. To date, chemical treatment approaches have been, for the most part, developed in an ad hoc fashion by commercial interests. Moreover, the field seems confusing because of the many different names given to that class of techniques wherein a relatively harmless chemical(s), usually liquid, is reacted with the hazardous waste to render it harmless enough so that it no longer has to be managed as a hazardous waste. For example, some speak of chemical fixation, chemical stabilization, encapsulation or chemical treatment. Although no standard names, definitions or tests to reveal the effectiveness of such techniques exist, treated materials were evaluated by the California Waste Extraction Test procedure (WET). This test differs from the traditional U.S. EPA-Extraction Procedure toxicity test in that treated material is ground so that it will pass through a 10 mesh sieve and then is heated 20-40 °C for 48 hr in citric acid instead of acetic acid for 24 hr.

The successful development and implementation of this technology involved the collaboration nd integrated efforts of four

groups. These groups included an industry which had a problem and elected to find a solution through treatment rather than litigation, a university that assisted in the design and evaluation of the treatment, a state regulatory agency (Department of Health Services) which encouraged the development of a new treatment technology and supported the effort through a meaningful application of the regulations, and a company (Lopat Enterprises, Inc.) that was able to develop and produce a custom-blended chemical system that would prove to be effective in treating widely variable hazardous wastes.

NATURE OF THE PROBLEM

The 200 ton/day waste stream that required treatment was generated in the process of shredding cars. This material, commonly known as auto shredder residue, is a heterogenerous mixture of non-ferrous residuals remaining after an automobile has been shredded and the ferrous material removed. The size distribution ranges from fine sand-like particles of glass, plastic, metal, etc. to large pieces of seat cushions, dash boards, parts of tires, trim molding, etc. Parts of electrical components can also be found throughout the size distribution.

As a result of the shredding process, the residue also has a 30-40% moisture content. In addition, because of a high rate of bacterial action on its organic matter, interaction of iron fines, moisture and pressure resulting from depth of burden, large piles of residue behave similarly to compost piles and are prone to combustion. Once combustion occurs, the piles have been known to smolder for long periods of time.

Based on the California WET procedure, the soluble lead content of this waste stream is on the order of 100 to 300 mg/l. Consequently, the initial attention was focused on lead because it exceeded the California hazardous waste classification threshold of 5 mg/l. The scope was expanded further to include cadmium, zinc and PCBs. The levels of these constituents are as follows: cadmium, 0.8 to 4 mg/l; zinc, up to 2000 mg/l; and PCBs, non-detectable to 100 mg/l.

Since the residue was considered hazardous according to the California WET procedure, the state and local regulatory agencies required that it be managed as a hazardous waste, thereby preventing it from going to a normal municipal landfill for disposal. The unavailability of local hazardous waste options required that it be trucked out of state at a considerable cost. It is interesting to note that the material satisfies the U.S. EPA requirements so that it can be considered a nonhazardous waste in states other than California.

TREATMENT METHODOLOGY

A successful treatment system had to satisfy the following constraints: (1) the treated material had to be rendered nonhazardous according to the California WET procedure, (2) the treatment had to be economically justifiable, and (3) because of the regulatory burdens affiliated with becoming a treater of hazardous waste, the material had to be rendered non-hazardous in the process line in order to avoid evoking the hazardous waste permit regulations. After rejecting several chemical treatment techniques such as the direct application of caustic soda and several high pH commercial chelating agents, a treatment system utilizing silicates was developed. The motivation for selecting silicates is that the technical and commercial literature indicate that they are effective in some applications and they are relatively harmless and readily available commercially.

A commercial silicate blend known as K-20TM/Lead-in-Soil Contaminant Control System (K-20TM/LSC), developed and manufactured by Lopat Enterprises Inc., of Wanamassa, New Jersey, was selected because of its ability to be custom-blended as needed for a particular application.* Typically, the K-20TM/LSC System consists of an equal mixture of a silicate solution of varying viscosity and a "catalyst" which usually contains a dispersing agent. Typically, the K-20TM/LSC mixture is prepared just prior to use from the components, i.e., part A contains the silicate blends and part B contains the catalyst. The ratio of parts A and B utilized depends on the mixture of the silicate and the particular requirements of the field application. In this application, a 50/50 ratio of A and B provided the greatest costeffectiveness and ease of use in the field.

The treatment is completed by mixing the silicate wetted residue with a cementitious material such as lime, PozzalimeTM, portland cement, kiln dust or fly ash. To satisfy the previously mentioned treatment goals, it was necessary to optimize the custom blend of K-20TM with the proper amount of cementitious material so that an effective treatment methodology could be achieved which provides the necessary mitigating characteristics to render the residue in compliance with California standards for nonhazardous wastes.

The treated material must be allowed to cure. Residues which are damp after treatment may require one to two days for drying and curing. Several mechanisms have been postulated for the efficacy of the technology. In the case of a heavy metal contamination such as lead, it is believed that a lead metasilicate is formed which is an insoluble precipitate. The results suggest that the K-20TM/LSC silicate system deeply penetrates into the waste material and causes tight bonding.

The development of the treatment system for the 200 ton/day residue stream began with a series of laboratory studies in which 100 lb samples were treated by a process of preconditioning through screening followed by applications of various levels and blends of K-20TM/LSC and lime in order to achieve a desired level of treatment and cost-effectiveness. In this case, a custom K-20TM/LSC blend was created which optimized the treatment of lead.

Basically, the custom K-20TM/LSC blend plus lime resulted in passing the California WET procedure at 5 mg/l at a cost of \$25 to \$30/ton treated. However, independent studies by the Department of Health Services indicated that treating the predominant form of lead found in the residue (divalent form of lead oxide) to a level of 50 mg/l would be an acceptable standard for disposition in a municipal landfill. This decreased the treatment costs to approximately \$10/ton.

The laboratory proof of the concept determination was followed by a large-scale pilot plant at the site and the full-scale installation of the system. The configuration of the treatment system included an 8- by 20-ft screen (surplus equipment from a coal mining operation), a spray chamber for the K-20TM/LSC and water mixture on the undersize material and a pug mill for mixing.

Controls were developed which allowed equal mixtures of the K-20TM/LSC A and B solutions to be mixed on line with an appropriate amount of water and sprayed into a hopper receiving the screened undersized material. The screened oversize material did not exceed the hazardous waste threshold value for lead and, thus, did not require treatment. Approximately 50 to 60% of the weight of the incoming material to the screen was in the fines. The treated material was placed on a concrete pad to cure and, because of its non-hazardous character, could be taken to a conventional landfill for final disposal.

Unfortunately, the treatment without cementitious material does not adequately reduce the levels of cadmium and zinc. The design of the full-scale treatment system, however, included a provision for lime feeding at the midpoint of the pug mill mixer. The combination of K-20TM/LSC with a cementitious fixative brought all of the metal leachate values within acceptable levels according to the California WET procedure. For example, at a level of treatment of about \$20 to \$25/ton residue, the metal leachate values from the residues were reduced in the treated material, respectively, as follows: lead, 92 to 43 mg/l; cadmium, 3.4 to 0.2 mg/l; and zinc, 1900 to 240 mg/l.

EXPERIENCES WITH OTHER WASTES

Some preliminary work has been conducted for a national company having a major battery recycling plant in California. The first step in the recycling process involves the milling of the batteries; the milling essentially breaks apart the case and frees the internal components containing lead. During the milling operation, the plastic casings become impregnated with lead so that the waste stream is considered a hazardous waste in California. WET lead levels of 400 to 700 mg/l have been measured.

Our initial results with $K-20^{TM}/LSC$ and lime indicate that lead levels of 40 mg/l can be achieved at a cost of about \$100/ton. Plans are underway for field testing of the treatment through a modification of existing equipment in the process line.

Various sludges from industrial processing that contain large quantities of lead, on the order of 1 to 5%, are being subjected to the treatment. In one case, a 1 to 2% heterogeneous lead sludge, treated with custom blended K-20TM/LSC and lime, yielded results of about 140 mg/l by the WET procedure and 0.2 mg/l by the EP toxicity test. The approximate cost of the treatment was approximately \$100/ton. A large-scale field test is being considered to further refine the process and economics of treating the 1,500,000 gal of sludge.

A K-20TM/LSC System is being evaluated for a site containing 40 acres of soil contaminated with lead to a depth of about 10 ft. This site would be a prime candidate for a mobile on-site treatment system embodying this technology. Preliminary indications are that the soil can be treated with K-20TM/LSC and PozzalimeTM, resulting in essentially a soil-like material which can be back filled.

The treatment also has been applied to a sludge containing barium where the EP toxicity test levels were reduced from 400 mg/l to 36.5 mg/l barium at a cost of about \$70/ton of sludge. Soils containing 2000 mg/kg of arsenic and 1000 mg/kg of chromium were treated with K-20TM/LSC and lime to give a 75% reduction in arsenic and a 90% reduction in chromium. The respective WET procedure values were 97 mg/l and 22 mg/l. Preliminary results on incinerator ash are also encouraging; the treatment reduced lead levels from 17 mg/l to 0.05 mg/l on the EP toxicity test at a cost of about \$50/ton of ash.

CONCLUSIONS

This field-tested treatment methodology offers several unique

Lopat Industries, Inc. is the owner of U.S. Patent No. 4,475,951 issued Oct 9, 1984 and entitled "ENCAPSULATING SEALANT FOR THE TREATMENT AND PRESERVATION OF BUILDING MATERIALS" and is also the owner of a pending application on an improved composition for encapsulating waste products, as described herein, and co-invented by Dr. Charles D. Falk and Mr. Lincoln R. Davis, employees of Lopat.

advantages. Briefly, the silicate-based K-20TM/LSC mixture can be custom-blended to achieve certain desired results in terms of treatment level for a particular waste with concurrent cost effectiveness. In general, the volume increase of the treated material is small, and in some cases there is no volume increase. This is particularly important when the final disposal of residues must be considered.

It is also possible that certain treated materials could be cast into a form which would allow their reuse as feed stock in another manufacturing process. For example, consideration is being given to further treating auto shredder waste residue so that it can be used as a lightweight aggregate. Treated ash and certain sludges are being considered as material for concrete and brick making. Contaminated soils can be backfilled after treatment, thereby eliminating further disposal.

Preliminary results indicate that the treatment is capable of dealing with wastes having high concentrations of metal contaminents. The application of the technology is relatively straightforward so that it could be easily incorporated into a mobile treatment system.

Lime Treatment of Liquid Waste Containing Heavy Metals, Radionuclides and Organics

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ABSTRACT

Lime is well known for its use in softening drinking water and the treatment of municipal wastewaters. It is becoming important in the treatment of industrial wastewater and liquid inorganic hazardous waste; however, there are many questions regarding the use of lime for the treatment of liquid hazardous waste.

INTRODUCTION

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Under the proposed rule on Land Disposal Restrictions 40 CFR 260 of Jan. 14, 1986, there have been many changes and revisions for the disposal of liquid wastes. Liquid hazardous wastes, including free liquids associated with sludge, may no longer be put in a landfill without treatment. The current criterion for determining the "free liquids" is to use the Paint Filter Liquid Test (Method 9095) which was promulgated on Apr. 30, 1985.

The liquid portion (free liquids) of a sludge may not contain metals in a concentration greater than or equal to the following:

(Valence)	mg/l		
As(+3)	500		
As(+5)	500		
Cd(+2)	100		
Cr(+3)	500		
Cr(+6)	500		
Hg(+ 2)	20		
Ni(+ 2)	134		
Se(+ 4)	100		
Se(+6)	100		
Tl(+3)	130		

The metals listed above usually are found in an acidic medium and must undergo a treatment process before they can be disposed of in a landfill. The treatment of radionuclides and organic waste may also undergo some of the same steps outlined below:

Treatment Process

Neutralization ------ Solidification

One method of treating liquid waste containing metals is to use a neutralizing material. Lime often is recommended because the calcium cation is an environmentally safe binder, since most of the salts formed at a neutral pH are insoluble after precipitation. Other alkalies such as sodium hydroxide form soluble salts after precipitation at a neutral pH and may cause an environmental problem when neutralizing an acidic metal waste.

Lime is often the chemical of choice for neutralizing acidic metal wastes because of its effectiveness and low cost. As the pH of an acidic metal liquid begins to increase because of lime treatment, most metal cations will precipitate into a hydroxide sludge of low solubility. Once this sludge has formed, it must undergo further treatment to insure that the metallic sludge is completely harmless to the environment.

On May 9, 1985, the U.S. EPA Office of Solid Waste and Emergency Response issued a Statutory Interpretive Guidance on the treatment of bulk hazardous waste. The agency has prohibited the use of an absorbent material that does not chemically stabilize or solidify a bulk hazardous waste. Examples listed as absorbents by the U.S. EPA are vermiculite, fuller's earth, bentonite, fly ash, fine-grained sand, shredded paper and sawdust.

The material specified for treatment is an adsorbent that "binds the liquid waste through a chemical reaction (e.g., hydration) rather than through a physical process." The two listed stabilization adsorbents are portland cement and pozzolans and lime.

When considering the cost of using an adsorbent, pozzolans and lime are always less expensive than portland cement. Pozzolanic adsorption is based on the reaction of lime and a finegrained siliceous material (e.g., fly ash) that combines to form a cementious solid.

Currently some generic and patent solidification techniques are used for the adsorption of liquid waste.'

PROCESSES

Neutralization and Precipitation

Both neutralization and precipitation are chemical processes in which a metal cation reacts with a hydroxide anion. This is the process of adding an hydroxide ion which then precipitates the metals.

The process of coagulation is both a physical and chemical process. Through the attraction of cation for anions, the suspended solids group together to form a floc. This flocculation is accomplished through the process of small particles colliding together under the mild turbulent conditions found in a stirred tank. Next, all of the precipitated material can be removed from the stirred tank to yield a material with a concentration of 20-50% solids.

The process of precipitation can be reversed by mixing the sludge with a low concentration of acid at pH = 5.0. The addition of lime to an acidic metal waste creates a hydroxide sludge, while the further addition of acid to this sludge brings down the pH to produce an acidic metallic waste. Hence, once an acidic metallic sludge has been treated with lime, it must undergo further treatment to prevent the leaching of metals.

Solidification of Inorganics

To render this material harmless to the environment, it is necessary to go through the process called solidification. The distinction between absorption and adsorption defines whether a sludge is solidified. Absorption is a physical process that does not chemically stabilize a waste material; adsorption is a final chemical reaction that forms a cementitious precipitated sludge.

As stated earlier, the U.S. EPA has prescribed the use of a pozzolan and lime as an effective chemical stabilizing material. The metal sludge in the presence of free water will combine with more lime plus the addition of fly ash to form a solid block. The lime reacts with fine-grained siliceous material, and the metal hydroxide then becomes part of the structure. This is the general process for inorganic waste treatment. The process treatment is identical for radionuclides.

Organic Waste Treatment

Organic wastes, however, may have a neutral pH, and the process of neutralization and precipitation does not occur. Solidification of organic waste occurs when the organic waste becomes part of the lime-pozzolanic material.

TYPES OF LIME FOR LIQUID WASTE TREATMENT

Many types of limes are available for neutralization, precipitation and solidification. The two main categories of lime are quicklime and hydrated lime. Quicklime consists of calcium and magnesium oxide from the calcination of limestone. There are three forms of quicklime currently available in this country:

- High calcium quicklime—usually containing 90 to 95% calcium oxide and 0.5 to 2.5 % magnesium oxide.
- Dolomitic quicklime—usually containing 55 to 60% calcium oxide and 35 to 40% magnesium oxide.
- Magnesium quicklime—usually containing 85 to 90% calcium oxide and 5 to 10% magnesium oxide.
- Commercial hydrated lime—is a dry powder obtained by treating quicklime with sufficient water to satisfy its chemical affinity for water, thereby converting most of the metal oxides to metal hydroxides.
- *High calcium hydrated lime*—high calcium quicklime produces a hydrated lime usually containing 72 to 74% calcium oxide and 23 to 24% water.
- Dolomitic hydrated lime (normal)—under atmospheric hydrating conditions, only the calcium oxide fraction of dolomitic quicklime hydrates, producing a hydrated lime of the following chemical composition: 46 to 48% calcium oxide, 33 to 34% magnesium oxide and 15 to 17% water.
- Dolomitic hydrated lime (pressure)—this lime is produced from dolomitic quicklime under pressure, which results in hydrating almost all of the magnesium oxide as well as all of the calcium oxide, producing the following chemical composition: 40 to 42% calcium oxide, 29 to 30% magnesium oxide and 25 to 27% water.

PRECIPITATION OF METALS

Since the overall steps are clarified, the detailed process of inorganic and organic waste treatment can be explained. The following shows the pH at which metal cations begin to precipitate:

Ion (Valence)	ence) pH Ion (Valence)		pH
Fe(+3)	2.0	Ni(+2)	6.7
Al(+3)	4.1	Cd(+2)	6.7
Cr(+3)	5.3	Co(+2)	6.9
Cu(+2)	5.3	Zn(+2)	7.0
Fe(+2)	5.5	Mg(+ 2)	7.3
Pb(+2)	6.0	Mn(+2)	8.5

Fig. 1 shows the actual range of pH where neutralization and precipitation occur. Notice that zinc(+2) will completely precipitate at a pH = 8.4, while cadmium will not completely precipitate until a pH = 9.7 is reached.



LIME PRECIPITATION





Solubilities of Metal Hydroxides at Alkaline pH

The lowest solubility limit of a metal ion may not be reached until the pH of the particular metal sludge is 0.5 to 1 unit above the pH where complete precipitation occurs. A good example is the divalent zinc ion. The zinc metal will completely precipitate when a pH of 8.4 is reached. However, Fig. 2 shows that the minimum solubility of the zinc cation is reached at pH = 10. Also, if the pH of a metal sludge increases above pH = 12, the zinc cation will become more soluble. Therefore, the conclusion that all sludge will precipitate at the same pH is not true.

A sludge containing a combination of metals will have some metal cations in their most insoluble stage at the precipitating pH while other metal cations will not be as insoluble. But certainly these metals will be precipitated and insoluble as far as a sludge consistency is concerned. A good example is a waste sludge from a metal canning operation. The metal sludge will contain a variety of constituents, and the curve observed for maximum insolubility of the metals will show a shift from that indicated in Fig. 2.

The percentage precipitations of a metallic liquid waste with a lime treatment process are shown in Table 2 and Fig. 4 in Appendix A. Appendix A contains many examples of treatment applications for the precipitation of metals.

SPA Document



Figure 3 Relationship of pH and Radium-226 Concentration in Phosphoric Acid "Contaminated Water" Bench Tests

PRECIPITATION OF RADIONUCLIDES

This process is similar to the treatment of heavy metals. Traditionally, highly radioactive waste has been treated with the formation of a glass binder. This typical glass binder contains lime. Lime also precipitates radium, strontium, uranium and yttrium.

Removal of these elements is also dependent upon pH. A good example is uranium-228. At pH = 6, only 60% can be precipitated; at pH = 10, more than 95% of the uranium cation can be precipitated.

Radium-226 behaves in a similar manner. Its solubility curve in the presence of phosphoric acid is shown in Fig. 3. With lime treatment at a pH greater than or equal to 10, the maximum solubility of the radium ion is less than 0.25 pCi/l. Based on the general laws of chemistry, it can be easily postulated that elements 56 through 71 and elements 88 through 103 can be precipitated with lime at pH = 9 or above.

SOLIDIFICATION

Metals and Radionuclides

Metals and nonmetals can be solidified with a pozzolan and lime after the waste has been precipitated. Metal hydroxides and calcium salts will combine with fly ash and lime in the presence of water to form a cementious product. A good demonstration of this is to make a sample as shown below:

Final Solid = Lime + Fly Ash + Waste + Water

Lime = 5 to 15% by weight Fly Ash = 50 to 65% by weight Waste = 8 to 19% by weight

Water = 10 to 60% of original sludge by weight

Organic Waste Treatment

For an organic sludge, lime and fly ash are used to solidify the organic waste. A good example is to make a sample. The typical mixture ratio for the final treated solid is shown by the following equation:

Final Solid = Lime + Fly Ash + Waste + Water

Lime = 5 to 15% by weight Fly Ash = 50 to 65% by weight Waste = 8 to 19% by weight Water (for binding reaction) = 10 to 20%

APPENDIX A: EXAMPLES OF MATERIALS THAT CAN BE TREATED WITH LIME

Metals

Lime can be used for the treatment of potable water to meet National Interim Primary Drinking Water Contaminant Levels. Also, lime can be used to treat a liquid hazardous waste containing metals. Under the new U.S. EPA guidelines for the disposal of liquids containing heavy metals, lime is the material of choice for neutralization and precipitation. The following table compares the various regulatory limits for the treatment of an aqueous medium.

Table 1 Treatment of Metals in an Aqueous Medium

	MCLs: Nat'l EP Toxic Interim Prim. Test Max. Drinking Water Levels for Max. Contam- Solid inant Levels Waste		California List for Liquids in a Hazardous Sludg e	
Arsenic, $(As + 3, As + 5)$	0.05	5.0	500	
Barium, (B + 2)	1.0	100		
Cadmium (Cd + 2)	0.010	1.0	100	
Chromium, (Cr + 3)	0.05	5.0	500	
Lead, (Pb + 2)	0.05	5.0	500	
Mercury, (Hg + 2)	0.002	0.2	20	
Nitrate (NO - 3)	10			
Nickel, (Ni + 2)			134	
Selenium (Se + 4, Se + 6)	0.01	1.0	100	
Silver (Ag + 2)	0.05	5.0		
Thalium, (Tl + 3)			130	
Fluoride, (Fl - 1)	2.4			

Description of Neutralization Processes

Arsenic

The first cation on the list is arsenic; it can be found either in

the As(+3) (arsenite) or As(+5) (arsenate) valence state.

Aluminum sulfate (alum) or ferric sulfate coagulation at a concentration of 20-30 mg/l can achieve 90% removal of As(+5) at a concentration of 0.3 mg/l. At a pH greater than or equal to 10.8, lime can remove 95% of a liquid containing 0.1 10.0 mg/l of arsenate.

Arsenite [As(+3)] is more difficult to coagulate. Alum (30 mg/l) can only remove 20% at a pH between 5.5 and 9.0, while ferric sulfate (30 mg/l) removes less than 60% of 0.3 mg/l of arsenite.

Lime is more effective at a pH greater than or equal to 10.8 to remove 70% of 0.3 mg/l of arsenite.

With chlorine, arsenite can be oxidized to arsenate. However, in highly organic water, this promotes the formation of chloroform or tri-chlorinated methane. Hence, the use of chlorine to oxidize arsenite to arsenate for greater removal can be a disadvantage to a treatment scenario.

Barium

Barium is an important metal contaminant. Alum and ferric chloride coagulation are not effective for barium removal.

Lime softening can achieve greater than 90% removal of Ba(+2) in the pH range between 11 to 10 in a concentration of 7-8.5 mg/l of Ba(+2).

Cadmium

Cadmium, a well known industrial contaminant, is found in the +2 valence state. Lime softening can achieve a 78% removal of a 0.3 mg/l of cadmium in the pH range of 8.5 to 11.3. Cadmium is extremely soluble below pH = 7.

There is evidence that cadmium coagulation with dolomitic lime is 99% efficient at removing cadmium. This effect was reported by Schiller and Khalafalla in "Magnesium Case for Improved Metals Removal."

Alum coagulation is reported to remove a maximum of 40% cadmium (0.3 mg/l) at pH = 8. However, in turbid water, alum coagulation can drop to 20% of cadmium concentration. Ferric sulfate can remove 90% of 0.3 mg/l of cadmium at pH = 8. However, at pH = 7.2, cadmium removal drops to 20%.

Chromium

Chromium is found in two valence states: Cr(+3) and Cr(+6). In an aqueous solution, Cr(+3) will exist as a cation and Cr(+6) in an anion form as $Cr_2O_4(-2)$ and dichromate $Cr_2O_7(-4)$. The Cr(+6) hexavalent form is the most toxic and the most likely pollutant in water.

Lime, alum or ferric sulfate are all capable of removing chromium [Cr(+3)] in excess of 90%. With a pH between 10.6 and 11.3, 98% removal of 0.15 mg/l of Cr(+3) can be achieved by lime coagulation.

For Cr(+6) removal, it is better to reduce the Cr(+6) with ferric sulfate. As ferrous iron oxidizes to ferric iron in the formation of ferric hydroxide floc, the precipitate of chromium hydroxide is formed. After the ferrous sulfate is added, sufficient time should be given for the reduction of Cr(+6) to Cr(+3). A 99% removal of Cr(+6) can be achieved with pH adjustment after the reduction process.

Lead

The carbonate and hydroxide forms of lead are very insoluble. Ferric sulfate and alum coagulation can achieve 97% removal of a lead concentration of 0.15 mg/l. At higher lead concentrations, alum can only achieve 80% removal, while ferric chloride can still achieve high removal.

However, lime can remove more than 98% of a 0.15 mg/l Pb(+2) in a pH range between 8.5 to 11.3.

Mercury

Mercury is found in two forms of its valence +2 state. The inorganic form is known to be less toxic and will be described first. Alum and ferric chloride can be used to coagulate Hg(+2) (inorganic). Ferric sulfate coagulation is best at a pH equal to 8 for 97% removal of 0.05 mg/l of Hg(+2) (inorganic). Alum coagulation is less effective; at pH = 7, a maximum of 47% of Hg(+2) (inorganic) of 0.05 mg/l can be removed.

Lime is very effective for inorganic Hg(+2). In the pH range of 10.7 to 11.4, 60 to 80% of a 0.5 mg/l Hg(+2) can be removed. At pH = 9.4, only a 30% removal can be expected.

The organic form is more commonly found and is more toxic. Organic Hg(+2) is much harder to remove than the inorganic compound. In turbid water, alum and ferric sulfate can remove up to 40% of the Hg(+2) present. Lime is not an effective coagulant for organic Hg(+2) at any known pH.

Selenium

Selenium is found in two valence states, Se(+4) (selenite) and Se(+) (selenate). Selenium can be found in an aqueous solution as $SeO_3(-2)$ (selenite) or $SeO_4(-2)$ (selenate).

Ferric sulfate is most effective at pH = 5.5 for an 85% removal of 0.03 mg/l Se(+4). At a higher pH, removal of selenium decreases. Alum coagulation is less effective with a maximum removal of 32% of a selenite.

Lime can remove up to 35% of a 0.03 mg/l Se(+4) at pH = 11.

At a low pH = 5.5, ferric chloride is more effective for Se(+4); at pH greater than or equal to 11, lime is more effective.

Silver

Silver is found in the valence state Ag(+2). Alum and ferric sulfate coagulation is effective at a pH range between 6 and 8 for a 70% removal of 0.15 mg/l of Ag(+2) in an aqueous waste.

Lime is more effective for Ag(+2) coagulation; at pH \ge 11.5, 90% of 0.15 mg/l of Ag(+2) can be achieved.

Nickel

The most common form of nickel is (+2) valence state. When lime is added to nickel, the hydroxide of nickel will precipitate very well. At a pH between 9.5 to 10.0, the solubility of nickel hydroxide is 0.01 mg/l.

Copper

A common valence state of copper is the (+2) valence state. In the pH range between 7.0 and 11.0, the hydroxide solubility of Cu(OH) is 0.05 mg/l.

Zinc

Lime can also do a tremendous job in removing zinc from a waste stream. Zinc is commonly found in the (+2) valence state. Zn(OH)₂ in the pH range of 9 to 11 has a solubility of 1.0 mg/l.

Inorganics

Fluoride

Fluoride is not a metal; however, it is found to be a naturally occurring contaminant in the raw water of many communities. There is considerable controversy over the allowable limit of fluoride [F(-1)] in drinking water. An old argument has been that in low concentrations, fluoride is needed for the prevention of dental decay.

The maximum fluoride level allowable in drinking water is set at approximately 2 mg/l at 63 °F. Fluoride normally is removed during potable water treatment as a side reaction.

$$2F(-1) + (Ca(OH)_2 \longrightarrow CaF_2 + 2OH(-1))$$
 (1)

Phosphate

Phosphate is an industrial pollutant that is known to cause eutrophication of fresh-water lakes when in a high concentration. A pH equal to 11 must be reached to reduce phosphate concentration significantly. A concentration of 300 mg/l of Ca(OH)₂ can reduce residual phosphate to below 5.0 mg/l. Below a pH of 11, the common resultant phosphate residue is tricalcium phosphate Ca₃(PO₄)₂.

At a pH greater than 11, the primary compound formed is hydroxylapatite $[Ca_5OH(PO_4)_3]$. Hydroxylapatite will form a microfloc and may be treated with a coagulant.

Also, by using lime to achieve a pH of 11.0, the chemical oxygen demand (COD) of a wastewater can be reduced from 400-600 mg/l to a level below 200 mg/l.

Sulfite and Sulfate

Sulfite (SO_3) and sulfate (SO_4) are the common by-product ions of reactions with sulfurous and sulfuric acid. These ions also are the by-product of sulfur emissions from coal burning power plants. Currently, there is an excess of 1.3 million tons of lime for the treatment of these two ions. Calcium sulfite is considered to be slightly soluble, while calcium sulfate is considered relatively insoluble. The sulfate ion often is found in pickle liquor sludge. Four examples are given below.

- Pickle Liquor is classified as RCRA waste K063. Treating pickle liquor with lime results in the formation of three common calcium salts: $CaSO_4 \ 1/2(H_2O)$ Plaster of Paris; $CaSO_4 \ 2(H_2O)$ gypsum; $CaSO_4$ anhydrite. The other compounds are metal hydroxides such as $Fe(OH)_2$ and $Fe(OH)_3$. A common treatment method is to use fly ash or cement kiln dust along with an excess of lime (3 parts lime; 1 part cement kiln dust; 20 parts acid sludge by weight). In this treatment scenario, the neutralization, precipitation and solidification occur in one step.
- Gold Mining Draining—in the gold industry, the gold ore often contains pyrite at a concentration of 9 g/ton. The pyrite content may contain between 1 and 3% sulfur. The pyrite bacteriologically oxidizes to yield sulfuric acid. This oxidation process is similar to the acid mine drainage found in the coal mining industry where pyrite is also a contaminant. Lime is the preferred material for the neutralization of this acidic waste.
- Coal Mining Drainage—coal mining operations often have tremendous amounts of acid drainage because coal contains



(2) Organic



pyrite and marcasite. When a coal pile is exposed to oxygen, the pyrite (FeS₂) will oxidize to produce acid (H+), ferrous iron (Fe+2) and sulfate (SO₄²). The ferrous iron will oxidize to ferric iron as shown below.

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2Fe^{-2} + 4SO_4^2 + 4H^+$$
 (2)

$$4Fe^{+2} + O_2 + 4H^{+} - 4Fe^{+3} + 2H_2O$$
 (3)

$$Fe^{+3} + 3H_2O \longrightarrow Fe(OH)_3 + 3H^+$$
 (4)

Hence, hydrated lime [Ca(OH)₂] will undergo the following reaction with pyritic acid mine drainage:

$$2Fe^{+2} + 2SO_4^2 + 2Ca^+ + 4OH \xrightarrow{} 2Fe(OH)_2 + 2CaSO_4$$
(5)

$$2Fe^{-3} + 6(OH)^{-} \longrightarrow 2Fe(OH)_{3}$$
 (6)

• Metal Recovery from Ore—Similarly, in the mining of copper and zinc, sulfuric acid is used to leach the metal from the ore. Lime is then used to treat the spent sulfuric acid waste.

Table 2 Metal Hydroxides: Removal of a Particular Metal in a Given pH Range

Netel's Bydroxids:	What is the metal that c range.	removel of a an be expec	particular t at 6 gives pH
ç	Impurity oncontration	<u>, i</u>	Removel <u>Efficiency</u>
Arsenite (+3)	(0.3 mg/1)	<u>≥</u> 10.8	701
Arsemate (+5)	(0.1-10.0 mg/1)	<u>></u> 10.8	95 X
Barium (+2)	(7-8.5 mg/1)	11 5 ارد	902
Cadaium (+2)	(0.3-10.0 mg/1)	.5_ يارد11.3	981
Chromium (+3)	(0.15 mg/1)	11 .3_1210 .6	981
Chromium (+6) B ma	est to reduce vi intain 8.5≥p8≥7	th ferrous su so that a flo	lfate and then t may form
Lesd (+2)	(0.5 ag/1)	11.328ر28.5	981
Ng(+2) imorganic	(0.5 mg/1)	11.4	701
Eg(+2) organic		lime is not e	[fective
Se (+4) selemite*	(0.03 eg/1)	pR = 11	TOT
Se (+6) selemate		Line is not	effective
		<u>1</u>	Maximum <u>Concentration</u>
Za (+2)		pf = 10	0.8 ag/1
Cu (+2)		11 ≥₽≣≥ 7	0.05 mg/1
W1 (+2)		p# = 9.8	0.01 mg/1
Cr (+3)		pB = 8.0	0.01 mg/1
Cd (+2)		pH = 11.0	0.08 mg/1
Рь (+2)		pH = 11.0	0.1 mg/1

*Ferric Sulfate is more effective at pH = 5.5 for 85% removal of 0.03 mg/l (Se+4).

APPENDIX B: RADIONUCLIDES

A common example of radionuclides from industry is the mining of phosphate for the production of fertilizer. Radium-226 is a common by-product associated with the mining of phosphate. Radium-226 can be removed through the process called double liming. The curve of precipitation versus pH for Radium-226 is given in graph 3.

 Table 3

 Efficiency of Removal Percentages, Radioactive Elements

Radioactive <u>Element</u>	pH For Best <u>Removal</u>	Efficiency o <u>Removal</u>	
Radium-226	pH>10	90 X	
Strotium-90	pH>10	96X	
Uranium-228	bR5 10	95X	
Yttrium-91	pH>10	98 X	



Figure 5 Radioactive Elements Precipitation

APPENDIX C: ORGANIC WASTE TREATMENT

The following information is taken from a patent granted to Conversion Systems Inc..³ The following is a description of organic sludges that can be treated with a pozzolan and lime.

1. Petroleum Sludge from Petroleum Refinery Units, pump leakage, surface runoff, spilled lubricants and waste liquids from housekeeping maintenance tasks (pesticide residue). This sludge will often compromise some of the following organic fractions:

On a wet weight basis, 20% sludge can be mixed in with the pozzolanic material.*

- A. Alkanes
 - 1. Octane (constituent of gasoline)
 - 2. Nonanes
 - 3. Decanes
- B. Cycloalkanes
 - 1. Cyclooctan (constituent of gasoline)
- C. Alkyl benzenes
 - 1. Ethylbenzene
 - 2. Propylbenzene
- D. Kerosene
- E. Furnace Oil
- F. Diesel Oil
- G. Aromatics (usually C_6 to C_{12})
- H. Polynuclear Aromatics

2. Acrylic Emulsion Waste from the production of acrylic resins (e.g. acrylate) and emulsions.

On a wet weight basis, 14% sludge can be mixed in with the pozzolanic material.*

A. Acrylic Paint Sludge

3. *Watery Waste* from demilitarized nerve gas and obsolete chlorinated pesticides decommissioned by the U.S. Army. These watery wastes contain *some* of the following:

On a wet weight basis, 20% sludge can be mixed in with the

pozzolanic material.*

- A. Aldrin
- B. Isodrin
- C. Dieldrin
- D. Endrin
- E. Diisopropylmethylphosphonate F. Dimethylphosphonate
- G. P-Chlorophenylmethylsulfoxide
- H. P-Chlorophenylmethylsulfone

4. Coking tar which is the by-product from the quenching of volatile gas during the coking process. Coking occurs when coal undergoes destructive distillation. Coking tar is composed of the following various organic materials:

On a wet weight basis, 20% sludge can be mixed in with the pozzolanic material.*

- A. Benzene
- B. Toluene
- C. Xylenes
- D. Cumenes
- E. Coumarone
- F. Indene Naphthalene
- G. Acenophthene
- H. Methylnaphthalenes
- I. Fluorene
- J. Phenol
- K. Cresol
- L. Pyridine
- M. Picolines
- N. Anthracene
- O. Carbozole
- P. Quinolines
- Q. Phenanthrene

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*Care should be taken that the sludge containing greater than 8% by weight of any single organic compound listed may take longer than 28 days to reach the maximum strength developed in the pozzolanic reaction. A good example of this is the rule that when sugar is added to pozzolans or portland cement, the reaction is retarded but the cementious reaction does go to completion.

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Demonstration of Land Treatment Of Hazardous Waste

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ABSTRACT

Using the upper soil zone to manage wastes has been referred to as landfarming, land spreading, land disposal, land application, sludge farming and land treatment. The application of waste on soil has been practiced, particularly by the petroleum industry, for more than 30 years. On July 26, 1982, the U.S. EPA established performance standards for the treatment of hazardous wastes in soil under Subtitle C of RCRA. At this time, the term "land treatment" was officially adopted. Under the performance standards, the operator must demonstrate that the hazardous constituents in the waste are being degraded, transformed or immobilized in the soil treatment zone. Several guidance documents have been issued by the U.S. EPA on "how to" perform the demonstration.

Data from a land treatment facility used to dispose of hazardous oily wastes from a refinery in the northwest United States are presented. The data include concentrations of selected organic (e.g., naphthalene and benzene) and inorganic (e.g., arsenic and copper) compounds in the soil at depth below the treatment zone. These data indicate that the organic chemicals in the waste are being biologically degraded, transformed and volatilized in the soil while inorganic metals are being immobilized. Statistical analyses on samples collected at selected depths in the soil indicate that the hazardous constituents in the waste have not migrated below 2 to 3 ft from the surface. Furthermore, calculations indicate that typically more than 90% of the organic compounds applied are being degraded. The unit life of the facility is limited to 20 to 30 years by the accumulation of metals in the soil that may affect revegetation at closure. Techniques to improve degradation including tilling, fertilization and applications rates and methods are discussed. Finally, applicability of land treatment for other hazardous wastes is discussed.

INTRODUCTION

The petroleum industry has used the upper soil zone to manage waste for more than 30 years. The incorporation of waste into the soil will be referred to in this document as land treatment. Currently, the treatment of hazardous wastes in soil is regulated under Subtitle C of RCRA. Some of the major performance standards contained in these regulations include:

- Control of run-on and run-off for 24-hour, 25-year storm
- Control of particulate matter by wind dispersion
- Unsaturated zone monitoring of both soil and water on a regular frequency
- Maintenance of the treatment zone no more than 5 ft below the surface and at least 3 ft above the seasonal high water table
- Demonstration that the hazardous constituents in the waste are being degraded, transformed or immobilized in the soil treatment zone

Many of the performance standards make the use of land treatment difficult. For example, in areas with a high water table such as those encountered at refineries in the northwestern United States, the standard of a 3-ft separation zone between the bottom of the treatment zone and water table is not attainable due to naturally high water tables, perched water zones or saturated, low permeable materials near the surface. Such sites have found it necessary to install subsurface drains or other artificial means to lower the water table.

The necessity to demonstrate that the wastes are being degraded, transformed or immobilized also has proven more complicated than indicated by the performance standard. In December 1984, the U.S. EPA issued a draft manual on how to perform the demonstration.¹ According to the Guidance Manual, the land treatment demonstration (LTD) should consist of the following initial evaluations:

- Reconnaissance Characterization of Waste Constituent Distribution in Soil—This evaluation includes collection and analysis of soil samples with depth in the land treatment facility and in a background area. Four background locations and one location per two acres of the treatment facility (minimum of six) are recommended in the Guidance Manual. At each location, eight samples over a depth of 20 ft are recommended. An elaborate compositing scheme is proposed resulting in 16 samples to be analyzed for an extensive list of parameters including the reduced Skinner list compounds (Tables 1 and 2). If greater than background concentrations are found, individual samples must be analyzed.
- Barrel Lysimeters or Field Plots—This evaluation includes conducting barrel lysimeter or field plots studies. The barrel lysimeters are composed of 55-gal drums that have been driven into the ground to obtain a relatively undisturbed soil mono-lith. The barrels are removed from the ground and waste is applied at three different rates. All tests are performed in triplicate. Both the soil and effluent are collected and analyzed with time for up to one year. In all, 12 barrel lysimeters (including three control lysimeters) and approximately 60 samples are recommended in the Guidance Manual.
- Toxicity Tests—This evaluation includes conducting toxicity tests on the water soluble fraction of both the waste and wastesoil mixtures. The proposed toxicity test uses a system to measure the response of luminescent bacterium to the various soluble chemicals by measuring the light output of the organism. The data are used to select maximum acceptable initial loading rates.

Other proposed evaluations include more intensive soil/pore water sampling, soil mapping and a 2-year follow-up study.

A new Guidance Manual has been written because of many

Table 1 Parameters for Land Treatment Demonstration

General	Netals	Organics			
Percent Vater	13 Skinner List Hetals	48 Skinner List Compounds			
Percant 011	(see Table 2)	(see Table 2)			
Percent Solids					
Ash					
Soluble Salts					
Total Nitrogen					
Total Phosphorus					
pā					
Total Organic Carbon					

Table 2 Appendix VIII Hazardous Constituent Subset for Petroleum Refinery Studies' (Reduced Skinner List)

Metals	Base/Heutral Organics (Cont.)
Antimony	Benzo(j)fluorantbene
Arsenic	Benzo(k)fluoranthene
Barium	Benzo(a)pyrene
Beryllium	Bis(2-ethylbexyl)phthalate
Cadmius	Butyl bensyl phthalate
Chromium	Chrysene
Cobalt	Dibens(a, h)acridine
Lead	Dibenz(a,h)anthracane
Nercury	Di-n-butyl phthalate
Nickel	Dichlorobensenes
Selenium	o-Dichlorobenzene
Silver	m-Dichlorobenzene
Vanadi uz	p-Dichlorobenzene
	Diethyl phthalate
	7,12-Dimethylbens(a)anthracen
Volatile Organics	Dimethyl phthalate
	Di-m-octyl phthalate
Benzene	Fluoranthene
Carbon Disulfide	Indene
Chlorobenzene	Wethyl chrysene
Chloroform	1-He thy inspiritual ene
1,2-Dibromoethane	Maphthalene
1,2—Dichloroethane	Phenanthrane
1,4-Dioxane	Pyrene
Methyl ethyl ketone	Pyridine
Styrene	Quinoline
Ethyl Benzene	
Toluene	
Xylenes	Acid Organics
Xylenes, m	
Xylenes, o & p	Benzene thiol
	Cresols
	o-Cresol
Base/Neutral Organics	p & m-Cresol
	2,4-Dimethylphenol
Anthracene	2,4-Dinitrophenol
Bens(a)anthracene	4-Witrophenol
Benz(b)fluoranthene	Phenol

adverse comments concerning the proposed LTD methods. The new Guidance Manual is currently in review and will focus more on actual sampling and contaminant fate modeling versus barrel lysimeter and toxicity testing. Overall, the best methodology used to perform an LTD may become a less important issue. On Jan. 14, 1986, the U.S. EPA proposed its Land Disposal Restrictions which may severely limit future land treatment of RCRA hazardous wastes.

In the next section, the results of the first step of an LTD, Reconnaissance Characterization of Waste Constituent Distribution in Soil, are discussed at one land treatment facility used to treat petroleum refinery waste in the northwestern United States.

CHARACTERIZATION OF WASTE CONSTITUENT DISTRIBUTION IN SOIL

The purpose of this phase of the LTD is to determine the depth

Methodology

As recommended in the Guidance Manual, a minimum of six locations were randomly selected on the treatment facility. In addition, two locations were selected to represent "hot" (visually black, high quantity disposal) and "wet" (standing water) spots. Four locations were also randomly selected in the background area. Continuous split spoon samples were collected at each location to a depth of 10 ft. In addition, a split spoon sample also was collected at 15 to 16.5 ft. Samples were selected for laboratory analyses based on field observations (e.g., bottom of oily material or change in lithology or horizon). Typically, the following samples were collected at several depths at each location for analyses:

- 0-12 in.
- 18-24 in.
- 30-42 in.
- 54-68 in.
- 90-102 in.

As shown, samples were composited over a depth of 6 to 12 in. that represented the amount of material needed to fill the laboratory bottles. Therefore, the samples actually were not composites but represented the entire 12 in. interval. No extensive compositing as proposed in the Guidance Manual was performed because in similar cases, statistical analyses indicated that individual samples would have to be analyzed to perform the required evaluations.

The resulting sampling program resulted in 67 samples (12 locations multiplied by 5 to 6 samples per location). Because of the large number of samples and the decision not to make composites, the cost of analyzing the samples for all parameters would be cost prohibitive (Table 1 parameters currently cost approximately \$2,500 per sample). Therefore, all samples were analyzed by the following screening techniques:

Screening Parameters	Methodology		
Aromatic Compounds (e.g., benzene, toluene, etc.)	Modified Method 8020 ³		
Polyaromatic Compounds (e.g., naph- thalene, phenanthrene, etc.)	Modified Method 8310 ³		
Metals (antimony, arsenic, chromium, copper, lead and zinc)	6010, 7060, 70413		
pH	12-2.64		
Electrical Conductivity	A.2.2.61		
Oil, water and solids	'		

As shown, the screening methods used for analyses of the organic compounds were gas chromatographic (GC) techniques (Method 8020) and high-performance liquid chromatographic (HPLC) techniques (Method 8310). To assure correct identification of the organic compounds and to verify that the correct screening parameters had been selected, 10% of the samples were analyzed for all of the parameters shown in Table 1. Organic compounds were analyzed by gas chromatographic/mass spectrometric (GC/MS) techniques and metals were analyzed by inductively coupled plasma (ICP) emission spectroscopic or atomic absorption (AA) spectroscopic methods.

Results

Organic Compounds

The GC and HPLC screening procedures were able to identify soils containing no contamination at similar or lower detection levels than the GC/MS method. This conclusion is illustrated by the following detection limits typically obtained:

		Detection Limits			
Compound	Units	GC/MS	Screen		
Anthracene	mg/Kg	0.16	0.01		
Fluoranthene	mg/Kg	0.16	0.1		
Toluene	μg/Kg	5	3		
Xylene	µg∕Kg	5	5		

Therefore, the screening techniques were able to accurately identify "clean" versus "contaminated" soils.

When highly contaminated soils were analyzed, however, the screening methods resulted in higher values than the GC/MS methods for the same compound. That is, the screening techniques were not in all cases able to resolve various compounds into individual components. Therefore, the reported value actually represented several compounds. This phenomenon is often referred to as "false positives." The concentrations reported by the screening techniques may be one to three orders of magnitude high.

Based on the analyses of percent of oil with depth, the average amount of oil remaining in the zone of incorporation (a depth ranging from 5 to 24 in.) was 11% by weight. Since 1977 when the treatment facility was first used, 15,000 tons of waste containing 4,300 tons of oil have been applied. Based on the quantity of oil remaining, 64% of the oil that has been applied has been degraded. Based on the analyses of the waste and the soil, the percent of degradation of selected compounds also can be calculated. As shown in Table 3, more than 99% of the volatile compounds have been removed from the soil. This loss is probably the result of both volatilization and biodegradation. The percentage degradation of the polyaromatic compounds ranged from 30 to 95%. The low degradation percent calculated for chrysene may be due to its extremely small concentration (near detection limits) found in the waste. No acid extractable organic compounds (e.g., phenols and cresols) were detected in the soil; therefore, their degradation rate would be 100%.

Table 3 Percent Degradation of Selected Compounds

Compound	Applied (tons)	Remaining (tons)	Percent Degradation
Benzene	3.81	0.034	99,1
Ithylbenzene	7.43	0.026	99.6
Toluene	23.29	0.032	99.9
0+p-Tylene	57.07	0.085	99.9
n-Xylene	23.74	0.089	99.6
1-methylnaphthalene	17.30	2.833	83.6
Maphthalene	6.84	0.325	95.2
benanthrene	25.42	6.288	75.3
Chrysene	2.13	1.479	30.4
Pyrene	2.14	0.407	80.9

Metals

Unlike the organic compounds, the metals in the waste applied to the field do not degrade; rather, they accumulate. Based on the analyses of the waste and soil samples, the quantity of metals applied to the treatment facility and remaining in the zone of incorporation can be calculated. As shown in Table 4, the amount of Cr and Zn applied is almost equal to the amount remaining on the treatment facility. If the sampling was representative and the volume calculations were correct, the values should be equal. For Cu, Pb and Sb, however, the calculations indicate that greater amounts of these metals exist on the treatment field than were applied. Some possible explanations for this observation include:

- The quantity of waste applied was actually greater than records indicate
- The calculated volume of soil containing the metals was too large
- The concentrations measured in the waste were larger in the past
- The concentrations measured in the soil were actually less

Even though the exact explanation is not known, it is clear that the metals are being immobilized in the zone of incorporation. This statement will be verified by the migration assessment presented in the next section.

 Table 4

 Quantity of Metals Immobilized

Metal	Applied (tons)	Measured on Facility (tons)	Background (tons)	Remaining ² (tons)
Ås	1.67	0.61	0.13	0.48
Cr	4.37	4.01	0.57	3.44
Pb	1.04	3.01	0.13	2.88
Sb	3.20	16.02	1	16.02
Cu	1.48	3.21	0.41	2.80
Zn	4.89	6.43	0.78	5.65

1 All values = Not Detected = $0.2 - 0.4 \,\mu g/g$

2 Remaining = Measured on Facility - Background

Migration Assessment

To determine if contaminants were migrating below the zone of incorporation of the waste, the concentrations of the metal contaminants were statistically compared at the 95% confidence level to the concentration measured in background soils. Statistical analyses for the organic compounds of concern could not be performed because values were not detected in the background soils. Therefore, any soil depths in the treatment facility having a concentration of any organic compound above the detection limit were assumed to have potential migration to that depth. The results of the comparison are shown in Table 5. Depths below the zone of incorporation of the waste (24 in.) with contamination above background concentrations are indicated by an "X" on the table. As shown, only two of the eight locations revealed significant migration below 24 in.

 Table 5

 Observed Concentrations Above Background

Location	Depth (inches)	Base/ Neutrals	Volatiles	Åş	Cr	Cu	Pb	Sb	Zn
1	16 - 30 36 - 54	X X	X		=				
2	-			none					
3				non					
4				non					
5	26 - 36	I							
6				BOD	·				
7				non	•				
8				none					

For location 5, the two compounds (phenanthrene and pyrene) found at the 26- to 30-in. depth were very near detection limits. The concentrations observed at depth at location 1, although near the detection limits, appear to be real and may have resulted from the installation of a lysimeter near this location.

As shown in Table 5, none of the metals hase migrated below the zone of incorporation, confirming the early statement that the metals are being immobilized.

Calculation of Unit Life

The concentrations of metals increase with time in the soil because the metals are being immobilized in the zone of incorporation. Therefore, the unit life of the treatment facility is limited by the amount of metals. Current acceptable concentrations at closure are shown in Table 6. As shown in this table, zinc and copper would drastically limit the life of the treatment facility to less than 5 years. The acceptable concentrations shown, however, are conservatively low and typically based on phytotoxic levels of the metal to specific plant species.

If moderate pH values above 6.5 are maintained, the metals such as copper and zinc typically are not available for plant uptake. If the criteria values are increased by a factor of two, the unit life increases to 20 to 40 years. Other possible alternatives include use of Cu- and Zn-tolerant plants, soil amendment or topsoil addition at closure.

Table 6 Calculated Unit Life

Parameter	Concentration in MALT (ug/g)	Acceptable Concentration (ug/g)	Applied Per Tear (1b)	Undit Life (yr)
Antiacry	 1156	_	1041.8	_
Acmenic	3	300	340.9	39.8
in riun	a 2	-	62.6	
Buryllium	0.322	30	0.12	22,000
Cardanium	1.72	3	1.6	50.6
Chromitum	273	1000	1170.1	32.2
Cotalt	ນ ²	200	6.7	1457
Capper	217	250	396.2	4.3
Land	1.00	1000	293.4	143.4
Nercury	0.12	-	0.41	
Ede)	412	100	52.4	58.4
Selecture	ю ^{2,3}	5	4.0	_4
Silver	0.3 ²	-	0.40	
Vernettum	57	300	27.1	849
Zinc	434	500	1335.1	2.6

1 Zone of Incorporation

2 Based on one sample

3 ND for Selenium = 60 µg/g

4 Cannot be calculated because the detection limit is greater than the acceptable concentration

Recommendations

As shown by the analyses of soil samples discussed in the previous section, the treatment facility is functioning properly and the hazardous constituents in the waste are being degraded, transformed or immobilized in the treatment zone. That is, the LTD has been completed and no further tests (e.g., barrel lysimeters) are necessary. The nonmigration of the hazardous constituents, however, will be verified by groundwater monitoring. This will assure that no migration from the treatment zone is occurring.

Even though the treatment facility is functioning properly, further improvements could be made. These are summarized in Table 7. By following the recommendations shown in this table, degradation will be enhanced further.

 Table 7

 Summary of Optimal and Observed Soil Properties

		Optimal Talue	Observed ¹		
Property	Unite		Average	Lange	Recommendation
C/N Ratios	<u>,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,</u>	60:1-100:1	100+1	50:1-180:1	Add nitrogen
C/P Batie		300+1-000+1	300+1	700+1-150+1	Add phosphorus
CEC	meq/100 g	>10	14.4	11-35	
pli	8.4.	6.0-8.0	6.6	4.8-7.4	Add lime
EC .	amhos/cn	G .0	2.0	0.6-3.1	
545		a		a32	
Aeration		aerobic		aerobic- nnaerobic	Deep ploving
Texture		<aox clay<="" td=""><td>112</td><td>15-282</td><td>•</td></aox>	112	15-282	•
Tenperature	*c	20-35	11	-	When possible, apply vastes from April - September
Noisture	I	30-90		20-100	Ploving, surface vater management and vhan possible apply vastes from April - September
Pater Table	f t) ti	3 feet below wateent some	-	1-4	Eliminate vaste application in lower portion and improve surface vater management

- - Not Determined or no action necessary

1 For Zone of Incorporation

2 Field Estimate

APPLICATION AT OTHER HAZARDOUS WASTE SITES

As previously stated, land treatment has been applied most widely at petroleum refineries, but several other RCRA and CERCLA sites also are using or proposing to use some form of biodegradation as part of closure.⁶⁻¹⁰ Treatment methods range from direct landfarming of waste to enhanced treatment in lined cells. In most cases, biodegradation has been shown to be the most cost-effective alternative with costs for treatment being between \$50 and \$100 per ton.

Some recent studies have shown biodegradation to be an ineffective technique for the treatment of the high molecular weight polyaromatic compounds and other compounds such as pentachlorophenol.^{11,12} This finding may be correct for some chlorinated compounds (e.g., dioxin); however, biodegradation is still a useful technique to reduce the volume of waste whether or not all the hazardous components are destroyed. After biodegradation is applied, some further treatment or containment may be necessary to achieve final closure.

The current alternatives to elimination of land treatment for all waste are limited. Some techniques such as waste recycling and solvent extraction technologies do show some promise; however, the resulting costs ultimately will be much higher than land treatment.

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The B.E.S.T. Sludge Treatment Process: An Innovative Alternative Used at a Superfund Site

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ABSTRACT

As the cost of cleaning up oily sludge impoundments increases, there arises a need for alternatives to the traditional means of sludge disposal. Several alternatives have been proposed and some are being tested, but the B.E.S.T.TM (Basic Extraction Sludge Treatment) process currently is being used to clean up a Superfund site near Savannah, Georgia. This full-scale 100 ton/day solvent extraction unit is being used to process approximately 10,000 tons of hazardous waste which were abandoned in 1975.

Resources Conservation Co., which owns the B.E.S.T.TM patents, is currently responsible for the cleanup of four acidic sludge ponds, contaminated filtercake and backfill lagoon material. The cleanup involves neutralizing the sludge from the ponds, screening the filtercake and backfill and then blending. The mixture then is processed through B.E.S.T.TM where it is separated into three factions: oil, water and solids. The oil is trucked off-site and sold as bunker fuel; the water is treated on-site and trucked to a large local wastewater treatment facility; and the solids, having been rendered non-hazardous, are disposed of on-site.

The B.E.S.T.TM process handles difficult-to-treat, emulsified oily sludge by breaking the emulsion and chemically separating the sludge into its components. These fractions (oil, water and solids) then can be handled separately, effectively and with less expense than using traditional means.

INTRODUCTION

Removal actions at hazardous waste sites generally have involved the excavation of site contaminated solids with their re-disposal at RCRA-approved landfills. Several recent developments have discouraged this "hole-to-hole" concept of waste site cleanup. The 1984 reauthorization of RCRA has limited land disposal of hazardous substances, and escalating landfill costs have made alternative technologies more feasible. Also, current U.S. EPA policy encouraged the use of innovative technology to avoid potential long-term public health and environmental impacts of off-site land disposal.

The U.S. EPA Region IV Superfund Emergency Response Program is implementing one such innovative approach at a waste site near the Georgia coast. Resources Conservation Co. (RCC), through the Emergency Response Cleanup Services Contract, currently is operating its Basic Extraction Sludge Treatment (B.E.S.T.TM) system at an abandoned oil re-refining site.

THE B.E.S.T. PROCESS

Resources Conservation Co. (RCC) developed and patented the B.E.S.T.TM process in the mid-1970s as a means of dewatering municipal wastewater sludges. The process was proven to successfully recover solids high enough in nutrients to be sold as animal feed or fertilizer. The low price of these products combined with the availability of inexpensive disposal alternatives made commercialization uneconomical at the time. The process was not developed further until 1984 when environmental legislation under RCRA escalated hazardous waste disposal costs. As a result, investigation of B.E.S.T.TM as a method for the treatment of oily sludges was initiated. After an intensive market study, RCC felt that it could provide a totally engineered processing plant at competitive prices to process listed and non-listed oily wastes (Table 1).

Table 1

RCRA Listed Hazardous Wastes

- K001 Creosote-Saturated Sludge
- K048 Dissolved Air Floation (DAF) Float
- K049 Slop Oil Emulsion Solids
- K050 Heat Exchanger Bundles Cleaning Sludge
- K051 API Separator Sludge
- K052 Tank Bottoms (Leaded)

Non-Listed Hazardous Wastes

- · Primary oil/solids/water separation sludges
- · Secondary oil/solids/water separation sludges
- · Bio-sludges
- Cooling Tower sludges
- HF Alkglation sludges
- Waste FCC Catalyst
- Spent Catalyst
- Stretford Unit Solution
- Tank Bottoms
- Treated Clays



Figure 1 B.E.S.T. Sludge Processing Unit on Location

In 1985 RCC built its first full-scale unit. This unit has a nominal capacity of 100 tons/day (wet throughput) and can handle sludges which contain up to 30% oil and up to 40% solids, without modifications (Fig. 1). Actual throughput, however, will vary with the actual composition and chemistry of the sludge.

B.E.S.T.TM was designed using modular concepts which makes the unit mobile. The ability to move the unit from site to site enables RCC to contract B.E.S.T.TM on a fee basis. By owning and operating B.E.S.T.TM units, RCC can contract cleanup work and free customers from capital expenditures.

The key to the patented B.E.S.T.TM process is the use of one or more of a family of aliphatic amine solvents to effectively break oil-water emulsions and thus release bonded water in the sludge. The aliphatic amines have a unique property: cooled below 20 °C they become completely miscible with water, but upon heating they become immiscible (Fig. 2). To take advantage of this "solubility" property, the B.E.S.T.TM process mixes the refrigerated amine solvent with the oily sludges. The solvent immediately liquifies the sludge and turns the mixture into a homogenous solution. Since the temperature is kept below the solubility line, solids are no longer bonded by the oil/water emulsion that was part of the original sludge and are released from the solution. Once the solids are removed, the temperature of the liquid fraction, which contains the oil, water and solvent, is heated above the solubility point and the water separates from the oil and solvent. The last step in the process is to remove the solvent from the oil using classical distillation.



Aliphatic Amine-Water Solubility

In Fig. 3, the B.E.S.T.TM process flow is diagrammed. The sludge is introduced to the solvent in a mix tank. The refrigerated solvent is agitated along with the sludge. This step constitutes the first stage of the extraction process. The mixture then is sent to a solid bowl decanter centrifuge where it is separated under the force of several thousands g's. A centrifuge is used to increase the rate of the solids separation and to insure that sub-micron-size particles are removed. It is critical to a successful operation that the first centrifuge obtain a very high capture rate and produce very clear centrate because any carryover of solids may result in the formation of "rag" layers in the decanter or emulsions in the oil product resulting in degraded oil. The solid cake from the first centrifuge normally contains approximately 50% solids by weight. These solids are sent to a second mixing tank and the solids are again washed with the solvent. By this time, the oil has been extracted from the solids twice and has been reduced to about 1% by weight.

The solids can be washed further by pressing them through a multiple stage countercurrent extractor which can reduce the oil concentration in the solids to less than 0.01%. If very low oil levels are not required, the countercurrent extractor may be by-passed. At this point, the solids are essentially free of oil and water and are sent to a second centrifuge where they are concentrated to about 50% by weight. This cake is sent to a dryer which is a hollow disc indirect heater that uses steam as the heating medium. Since the solvent has a lower heat of vaporization than water, the drying step requires less energy than if water were being

evaporated.

The centrate that leaves the first centrifuge is essentially free of solids and contains all the oil and water extracted from the raw sludge. This centrate, which is still cool and, therefore, in solution with the amine solvent, is heated in a series of heat exchangers to a temperature well above the solubility curve; thus, the mixture is in the immiscible region. This two-phase stream is passed through a decanter where the lower water fraction is separated and sent to a stripping column to remove residual solvent. The top fraction leaving the decanter is primarily the solvent containing oil extracted from the raw sludge. This top oil/solvent fraction is sent to a second stripping column where the solvent is recovered and the oil is discharged.

The overheads are stripped off as an azeotrope containing 10% water and 90% solvent by weight. These overheads are sent, along with the solvent vapors from the dryer, to a condenser from which the condensate is sent to a second decanter. In the decanter, the bottom water fraction is removed and recycled through the water stripper; what is left is pure recovered solvent. The recovered solvent is refrigerated and returned to the beginning of the process, and the cycle is repeated.

SITE HISTORY

The General Refining site located near Savannah, Georgia, was operated as a waste oil re-refining facility from the early 1950s until 1975. The sulfuric acid used to treat the oil produced an acidic oily sludge and oily filter cake as by-products. The sludge was disposed of in four unlined lagoons, and the filter cake was buried and stockpiled on-site.

An additional unlined lagoon that had been used as an oilwater separator subsequently was backfilled with filter cake and sludge. There was also waste oil stored in bulk tanks on-site. The total volume of waste has been estimated to be in excess of 10,000 tons.

Analysis of waste oil, sludge and filter cake revealed the presence of petroleum compounds and heavy metals including lead (16-10,000 ppm) and copper (83-190 ppm). PCBs were detected in all samples at low concentrations (<10 ppm). The lagoon sludge and associated water have a pH of less than 2. Lead, copper, PCBs, oil and grease detected in the groundwater beneath the site threaten nearby drinking water supplies.

To remedy the situation, site cleanup actions were initiated to stabilize the site, secure the facility and explore disposal alternatives. In evaluating disposal alternatives, consideration was



Figure 3 B.E.S.T. Process Flow Diagram

given to both on-site and off-site incineration, landfilling and an on-site solvent extraction process. The various methods were evaluated primarily on the basis of cleanup time and cost. With the exception of landfilling, all options offered an ultimate solution to the waste disposal problem at the site.

Because the B.E.S.T.TM solvent extraction process required neither major transportation costs (as in the case of off-site incineration) nor an involved testing and permitting process (as in the case of on-site incineration), it was chosen as the most suitable and cost-effective disposal option for this site.

A three-phase approach was implemented to identify any sitespecific problems that may have resulted in the system being incompatible with the wastes at the site. Phase I included detailed analyses of all waste streams and pond strata to identify treatment and disposal requirements. Pilot-scale testing was conducted during Phase II to evaluate each component to determine treatment system operating requirements. Phase III, which currently is underway, includes the mobilization and on-site operation of the mobile treatment system.

PROCESS OVERVIEW

Processing the hazardous waste at the General Refining site starts with front end materials handling (Fig. 4). As previously discussed, the filter cake and backfill material are screened independently from the sludge and placed in piles. The sludge is pumped out of the ponds and placed into large holding tanks. When the sludge storage tank inventory is reduced, the neutralization step begins.

Neutralization is accomplished by mechanically mixing the wastes with sodium hydroxide. The raw sludge is blended with the filter cake and backfilled lagoon solids until the mixture is homogenous and the pH is appropriate. This mixture, which is approximately 70% water, 10% oil and 20% solids, is pumped to the sludge storage tank where it is pumped to the B.E.S.T.TM and processed.

Since the ponds are stratified, free water from the ponds is pumped out separately into a holding tank which stores water to be processed by B.E.S.T.TM along with the sludge. Depending on the operating needs of B.E.S.T.TM, part or all of the free water can be pumped directly to Water Treatment, bypassing B.E.S.T.TM altogether.

The Water Treatment plant is a modular facility using twostage clarification. The first stage consists of acidifying the water and adding a flocculant and an oil/water emulsion breaker. Solids removal is accomplished in a contact clarifier. Lime is added to increase the pH, and alum is added to precipitate the heavy metals (in particular lead). Again, a contact clarifier is used to settle out



Figure 4 Process Overview

ludge materials. A centrifuge is used to dewater the clarifier inderflows, and the rejected water treatment sludge is returned to B.E.S.T.TM for retreatment.

Since the General Refining site is an inactive site, RCC was required to supply all required utilities except electricity and service water. RCC provided a mobile oil-fired boiler and a cooling tower instrument air module which provides the necessary steam, cooling water and instrumentation air for process equipment operation.

OPERATIONAL EXPERIENCE

The B.E.S.T.TM unit installation was completed in July 1986 at which time waste material was first introduced into the system. Although some mechanical problems have been encountered since system startup, the B.E.S.T.TM unit has consistently separated the sludge into fractions that meet or exceed contractual requirements.

The front end materials handling operation necessitated the use of several types of solids processing equipment. Since all site material was required to be less than 1/4 in. mesh, the solids pile of filter cake and backfill had to be screened. Difficulties were encountered meeting the 1/4 in. screening requirement. Original efforts were made to pass filter cake material through a 1/4 in. vibrating dry screen; however, the high moisture and oil content in the filter cake material adversely affected the efficiency of this operation by allowing formation of conglomerate material which would not pass through the screen.

A change was made from the vibrating dry screen to a 1/4 in. hammermill, which crushes material to a desired size. However, a 2 in. drag screen was required in conjunction with the hammermill to pre-screen metal and other objects that could damage the unit. This drag screen limits the rate of filter cake processing and may back up materials handling operations.

Screening of the sludge from the ponds, in contrast to the filter cake solids, has been successfully accomplished using a vibrating screen. The sludge is pumped from the ponds using a submerged double diaphragm pump into the vibrating screen where it is mixed with sodium hydroxide. The screened sludge and caustic drop into a mixing tank where they are mixed with the filter cake solids. This mixture is pumped into a storage tank to await treatment in B.E.S.T.TM. The consistent reliability of this equipment to handle this very difficult material (viscosities in excess of 1,000,000 centipoises) has been one of the successes at the site.

Unfortunately, the B.E.S.T.TM unit itself has not been free of mechanical difficulties. Three problem areas have been the centrifuge seals, the dryer solids conveying system and the control of the solvent stripper.

Triethylamine, the solvent which is used at the General Refining site, can be flammable in the presence of air. Therefore, all unit processes must be sealed from the atmosphere and kept under a nitrogen blanket. Since centrifuges are not inherently leak tight, special close tolerance seals were designed by the manufacturer. These seals were purged with nitrogen. Unfortunately, the seals never worked and when they failed they caused the bearings to fail. After many centrifuge outages, a suitable material for the seals was discovered, although some triethylamine continued to leak. A search for an appropriate seal design continues, although the centrifuges are now operational.

The successful conveyance of dried solids out of the dryer requires one to maintain a constant solids level at the solids exit chute and control the pressure in the dryer. The first design failed to achieve either requirement. As a result, the solids could not be removed from the unit without leaking triethylamine vapors accompanied by large amounts of hazardous dust. Two changes are being made to the dryer to alleviate the situation. A larger chute is being built with a level control to control the speed of the conveyor. In addition, the dryer will be uncoupled from the main condenser, making the dryer an independent unit process with its own condenser and pressure control. It is anticipated that these modifications will result in a controlled exit of solids from the dryer.

The solvent still controls originally were designed to control the energy balance of the stripping column with indirect steam heat to the reboiler which continuously heats the oil that is being circulated at the bottom of the column. Since the design is based on stripping triethylamine as an azeotrope, live steam was used to control the water balance in the column. Control of the live steam proved to be difficult. As a result, the live steam control was changed from a temperature-based control system to a proportional control system. RCC also is considering the use of a direct water injection design instead of the live steam design.

CONCLUSIONS

Land disposal is becoming a less viable answer to hazardous waste management. Consequently, the U.S. EPA is directing efforts toward innovative and alternate technology as exemplified by Resources Conservation Co.'s B.E.S.T.TM Solvent Extraction Process. This approach is necessary to develop more environmentally acceptable solutions to the hazardous waste problem. Although the Superfund Removal Program is oriented toward direct, effective results, it must be flexible enough to accommodate changing technology. In fact, due to its efficient approach, the Removal Program is better able to evaluate new technology in a cost-effective manner.

Although the cleanup at the General Refining site is still in its startup stages, the B.E.S.T.TM Solvent Extraction Process's ability to make the basic sludge separation as required indicates that B.E.S.T.TM does indeed represent a new technology and a real viable alternative.

DISCLAIMER

The authors are solely responsible for the views and opinions contained herein. The paper is neither an official statement by the U.S. EPA nor is it an endorsement of the views and opinions expressed or implied on the part of the authors.

Resources Conservation Co. is a subcontractor to Haztech, Inc., for all work at the General Refining site. Haztech, Inc. is responsible for the materials handling portion of the contract. RCC appreciates the assistance Haztech has provided on this project.

In Situ Air Stripping: A New Technique for Removing Volatile Organic Contaminants from Soils

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ABSTRACT

The contamination of soils and groundwater by past waste solvent handling and disposal practices has been identified as one of the major environmental concerns throughout the nation. Numerous industrial locations and abandoned hazardous waste sites on the National Priorities List are plagued with solvent-related contamination problems resulting from chlorinated volatile organics in the soil and groundwater. Due to the mobility and volatility of most chlorinated volatile organics, control of the contaminant source area is difficult and long-term impacts on groundwater quality are prevalent. The U.S. EPA and state environmental agencies have not established soil cleanup standards for volatile organics such as trichloroethylene, but recommended water quality criteria and primary drinking water standards have been used as a guide for hazardous waste remedial actions.

INTRODUCTION

While groundwater treatment is widely understood and practiced as a cleanup strategy, soil decontamination and treatment techniques still are regarded as innovative technologies. The primary accepted practices for treating volatile organic contaminated soils have involved either site isolation through capping or excavation with ultimate disposal in an appropriate landfill facility. In the future, however, land disposal of solvent-contaminated soils will become much more difficult or even impossible as the new RCRA amendments for secure land disposal become operative.

This paper describes a pilot-scale, field demonstration of an innovative technique for soil decontamination; that technique is in situ air stripping of chlorinated volatile organics from contaminated soils. WESTON conducted the pilot demonstration during a 14-week field program at a site comprised of sandy glacial soils where open burning of waste solvents had been performed periodically during a 30-yr period. Trichloroethylene (TCE) was utilized as the indicator monitoring compound to evaluate the overall effectiveness of the technology.

TCE had been found in the groundwater at the site at concentrations two to three orders of magnitude greater than the recommended drinking water quality criterion of 2.7 μ g/l while soil concentrations had been found to be as high as 5,000 mg/ kg. Due to the extensive soil contamination, an in-place soil treatment option (air stripping) was recommended as a potential source control remedial action for the site.

In situ air stripping required a pilot demonstration project before implementation as a full-scale remedial cleanup strategy. The pilot project was designed to demonstrate the feasibility of the technology and to develop design data for full-scale site remediation.

PROCESS DESCRIPTION

In situ air stripping involves the removal of volatile organics from a soil matrix by mechanically drawing or venting air through the unsaturated soil layer. The soils are gradually treated as the volatile organics are stripped from the soil particles; volatile compounds and soil moisture are driven into the air phase within the soil pore spaces. The in situ air stripping system must be designed and operated in accordance with the site-specific subsurface conditions to maximize the contaminant removal effectiveness.

While air stripping techniques have been applied on a limited basis for the removal of some chlorinated organics and light molecular weight hydrocarbons from contaminated soils, overall system effectiveness and design and operating parameters have not been previously established. During this pilot demonstration, we investigated the relationship between TCE concentrations in the soils and the air as well as the proper design values for the air stripping parameters of air flow rate and spacing of the extraction pipe vents. We also determined that the cost of fullscale remediation utilizing the technology is low in comparison to conventional remediation technologies (i.e., \$15 to \$20/yd³ of soil to be treated).

SYSTEM DESIGN AND OPERATION FOR AIR STRIPPING IN SOIL

The experimental apparatus for the in situ air stripping pilot demonstration was comprised of a pipe vent and forced air ventilation system installed in the unsaturated zone along with the necessary control mechanisms to monitor and sample the air stripping process (Fig. 1).

The pilot demonstration project utilized a gas chromatograph equipped with a photoionization detector (GC/PID) for on-line analysis of TCE in the exhaust gases.

The system shown in Fig. 1 is described below:

- *Pipe Vents*—perforated PVC pipes were installed vertically into the subsurface soils within the zones of contamination.
- Air Blowers—a closed forced-ventilation system consisting of lateral pipe manifolds connecting the pipe vents with air blowers was constructed. A separate manifold and air blower apparatus was used for the extraction and injection systems.
- Air Flow Control and Measurement—air flow measurement annubar meters were installed to monitor air flow rates on a continuous basis, and manifold valve arrangements were installed to control the air flow rate for the system.
- Exhaust Emissions Control—air emissions from the extraction manifold were passed through a vapor phase activated carbon unit prior to final discharge to the atmosphere.

- *Electric Space Heaters*—an electric space heating and thermostat control system was used in the small building housing the air blowers and instrumentation to supply a relatively uniform temperature of injection air.
- Automated Data Logging—an automated microprocessor data logging system was used to facilitate continuous monitoring of air flow rates, air flow pressures and temperatures.

Previous soil sampling and analysis performed at the site identified the likely presence of at least two TCE-contaminated areas resulting from past solvent burning activities. Two separate air stripping systems were installed at a depth of 20 ft at two contaminated areas. Each system used separate injection and extraction pipe vents, manifold pipes, air blowers and sampling and monitoring equipment.



Figure 1 Schematic of Pilot Study Apparatus for In Situ Air Stripping of Organics from the Sun

Pilot System No. 1 was designed to test air stripping of lowlevel TCE contamination identified in the soil of the smaller burn area (TCE soil concentrations of 5-50 mg/kg). Pilot System No. 2 was designed to investigate the air stripping technology within the more highly contaminated second burn area (TCE soil concentration of 50-5,000 mg/kg). Table 1 shows the basic design approach of the two pilot air stripping systems.

AVAILABLE DESIGN DATA

The design and operation of an in situ air stripping system is based upon the theory of gas movement in porous media. Air stripping applications at hazardous waste sites must address the chemical characteristics of contaminant migration as well as the characteristics of air flow and pressure in the subsurface soils. In situ air stripping, as a new technology, has received limited attention as a potential remedial action alternative, and previous investigations have established no design or operating parameters.

Design Basis for the Two Pilot-Scale In Situ Air Stripping Systems						
Pllot System No. 1	Pilot System No. 2					
Designed for lower concentrations of residual TCE contamination in soil (5 to 50 mg/kg TCE)	Designed for higher TCE con- tamination in soil (50 to 5,000 mg/kg TCE)					
Constant air flow rate system; approximately 50 ft ³ /min	Variable air flow rate system; 50 to 225 ft ³ /min					
20-ft spacing for extraction pipe vents	50-ft spacing for extraction pipe vents					

Table 1

TEST PROGRAM

Data were generated during the project to establish TCE removal rates, air blower pressure and flow rate characteristics, and subsurface pressure and distance relationships. The following general project tasks were performed to evaluate the effectiveness of in situ air stripping to TCE from soil.

Soil Sampling Program

The subsurface soils at each pipe vent location were sampled through auger/split spoon samplers to determine both TCE concentrations and soil characteristics. The soil from each system was sampled before and after the air stripping investigations to provide an order of magnitude estimate of TCE removals.

Exhaust Air TCE Sampling

The exhaust air from each system was analyzed for TCE using the on-site GC/PID. An automated switching and air purging arrangement was developed to retrieve hourly samples from each system. TCE concentration detection limits of 50 ppb were obtained, and exhaust air TCE concentrations as high as 350 ppm were measured during the project. The TCE air stripping trends were established, and mass removal rates were calculated.

Evaluation of Operating Relationships

The subsurface air flow dynamics and the radius of influence for pipe vent extraction systems were investigated. The vacuum maintained in the soil at various flow rates and radial distances was measured, and pressure drop relationships were developed to recommend air blower capacities and pipe vent spacings.

AIR STRIPPING RESULTS

Both in situ air stripping pilot systems were effective in consistently removing TCE and other volatile organics from the contaminated soils under investigation (Table 2).

In addition to analytical data relating to removal performance, design data were obtained. These data address the relationship between air pressure in the soil, air flow rate and vacuum pressure (head) at the blowers. This work can be used to design an in situ stripping system for other types of sites and site conditions.

 Table 2

 Comparison of TCE Air Stripping Results for the Two Sites

Pilot System No. 1 Results	Pilot No. 2 Results
Daily exhaust air TCE concen- trations exhibited generally de- creasing trends from a high range of 5-12 ppm early in the projects to the low range of 500- 800 ppb at the end, over a three-month period.	Daily exhaust air TCE concentrations remained essentially in the same range of 250-350 ppm during the project over a three-month period.
TCE mass removal trends re- sembled an increasing exponen- tial relationship with a cumula- tive TCE removal of about 2.2 lb from the residual soil con- tamination.	TCE mass removal rates resembled a linear increasing relationship as 22- 33 lb of TCE were removed each day during the project. Nearly 1600 lb of TCE were removed from the highly contaminated soils.
TCE removals of below 100 ppb in the exhaust air may have been achieved through continued system operation.	Similar TCE removal trends would have more than likely continued under further air stripping until TCE masses in the soil were significantly reduced. Only an estimated 10-20% of the TCE was removed from the soil during the short-term pilot test.

DISCUSSION

The pilot-scale air stripping program demonstrated the potential application of this technology as an in situ soil treatment strategy for remedial action cleanup of organically contaminated soil. The project demonstrated that volatile organics (i.e., trichloroethylene, 1,1,1-trichloroethane, dichloroethylene and toluene) can be effectively removed through the use of forced air ventilation systems such as the air stripping apparatus used in the investigations.

In situ air stripping may have application where volatile organic contaminants are of primary concern from a remedial action standpoint. However, each site will require separate design and optimization consideration. Using a site-specific optimization program, the relationships between air flow rates, soil vacuum conditions and air stripping system layout can be determined.

The U.S. EPA is presently evaluating the use of the technology at NPL sites to accelerate, in a cost-effective manner, the removal of volatile organics from soil. In addition, the application of the technology is being proposed as a means of minimizing potential off-site exposure to volatile organics to critical receptors prior to final remediation of contamination in the saturated zones.

We have utilized the technology for remediation at two sites involving propane and chlorinated solvents, respectively. In addition, several projects are in the planning stages to develop sitespecific design information at two sites contaminated with volatile organic solvents.

In Situ Vitrification — A Candidate Process For In Situ Destruction of Hazardous Waste

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INTRODUCTION

As management of hazardous materials gains increased attention in the United States, new, more effective technologies are being sought to immobilize and/or destroy the wastes either in situ for previously disposed wastes or at the waste generation site for newly generated wastes. The new RCRA and CERCLA legislation, combined with proposed rule-making by the U.S. EPA, is making landfill disposal very costly and is moving in a direction that will severely limit future land disposal. Further, the extended liability associated with future environmental impairment provides a significant corporate incentive to dispose and delist wastes within the plant or waste site boundary.

Pacific Northwest Laboratory (PNL) is developing a remedial action process for contaminated soils that is potentially significant in its application to these concerns. Although the process was initially developed to provide enhanced isolation to previously disposed radioactive wastes, recent tests have shown that many hazardous chemical wastes are also destroyed or immobilized as a result of the treatment. The process, in situ vitrification, was originally developed for the Department of Energy for radioactive waste material and more recently has been adapted for selected commercial clients for hazardous wastes.

In situ vitrification (ISV) is a thermal treatment process that converts contaminated soil into a chemically inert and stable glass and crystalline product. Fig. 1 illustrates how the process operates.

A square array of four electrodes is inserted into the ground to the desired treatment depth. Because the soil is not electrically conductive once the moisture has been driven off, a conductive mixture of flaked graphite and glass frit is placed among the electrodes to act as the starter path. An electrical potential is applied to the electrodes, which establishes an electrical current in the starter path. The resultant power heats the starter path and surrounding soil up to 2000 °C, well above the initial melting temperature or fusion temperature of soils. The normal fusion temperature of soil ranges between 110 and 1400 °C.



Figure 1 The In Situ Vitrification Process

The graphite starter path eventually is consumed by oxidation, and the current is transferred to the molten soil, which is now electrically conductive. As the vitrified zone grows, it incorporates nonvolatile elements and destroys organic components by pyrolysis. The pyrolyzed byproducts migrate to the surface of the vitrified zone, where they combust in the presence of oxygen. A hood placed over the processing area provides confinement for the combustion gases, and the gases are drawn into the off-gas treatment system.

PNL began developing ISV technology in late 1980 under the support of the U.S. Department of Energy. Since then, numerous experimental tests with varying conditions and waste types have been conducted.^{2,3,7} Table 1 describes the different scales of test units that PNL used in developing the technology. The successful results of the 43 bench-, engineering- and pilot-scale tests have proven the feasibility of the process. Also, economic studies have indicated that tremendous economies of scale are attainable with the ISV process.¹ This led to the commitment to design, fabricate and test a large-scale prototype unit. Its successful testing has demonstrated the field utility of the large-scale unit and has proven the initial economic projections.

Table 1 ISV Test System Characteristics

System Scale	Power (kW)	Electrode Spacing (m)	Vitrified Mass per Setting	No. of Tests
Bench	30	0.11	1-2 kg	4
Engineeri	ng 30	0.23 - 0.36	0.05 - 1.0 t	25
Pilot	500	1.2	10 - 50 t	14
Large	3,750	3.5 - 5.5	400 - 800 t	4

This report describes the large-scale ISV system, discusses its capabilities and summarizes the results of testing to date. PNL recognizes that ISV is not the solution to all hazardous waste management problems. But judiciously applied, ISV can offer technical and economic improvements to state-of-the-art remedial action technology. With understanding of the process design and functions, the waste manager can make sound judgments about the applicability of ISV to site-specific disposal problems.

PROCESS AND OPERATION DESCRIPTION

As already described, the melt grows downward and outward while power is maintained at sufficient levels to overcome the heat losses from the surface and to the surrounding soil. Generally, the melt grows outward to about 50% of the spacing of the electrodes. Therefore, if the electrode spacing is 5.5 m, a melt width of about 8.5 m would be observed under nominal conditions. The molten zone is roughly a square with slightly rounded corners, a shape that reflects the higher power density around the electrodes.

As the melt grows in size, the resistance of the melt decreases, making it necessary to periodically adjust the ratio between the voltage and the current to maintain operation at constant power. This is done by adjusting the tap position on the primary power supply to the electrodes. There are 14 effective taps that permit adjusting the voltage from a maximum of 4000 V to a minimum of 400 V per phase and the current from a minimum of 400 A to a maximum of 4000 A per phase. Operations follow the power equation $P = I^2 \times R$, where P is power, I is current and R is resistance.

The large-scale process equipment for in situ vitrification is depicted in Fig. 2. The process immobilizes contaminated soil and isolates it from the surrounding environment. Controlled electrical power is distributed to the electrodes, and special equipment contains and treats the gaseous effluents. The process equipment required to perform these functions is divided into five major subsystems:

- Electrical power supply
- Off-gas hood
- Off-gas treatment
- Off-gas support
- Process control

Except for the off-gas hood, all components are contained in three transportable trailers (Fig. 3): (1) an off-gas trailer, (2) process control trailer and (3) support trailer. All three trailers are mounted on wheels sufficient for a move to any site over a compacted ground surface. The off-gas hood and off-gas line, which are installed on the site for collection of the gaseous effluents, are dismantled and placed on a flatbed trailer for transport between the sites to be treated. The effluents exhausted from the hood are cooled and treated in the off-gas treatment system. The entire process is monitored and controlled from the process control trailer.

The off-gas trailer is the most complex and expensive of the three trailers. The off-gas treatment system cools, scrubs and filters the gaseous effluents exhausted from the hood. The primary components include: a gas cooler, two wet scrubber systems (tandem nozzle scrubbers and quenchers), two heat exchangers, two process scrub tanks, two scrub solution pumps, a condenser, three mist eliminators (vane separators), a heater, a charcoal filter assembly and a blower system.



Large-Scale In Situ Vitrification System

A major element of the off-gas support system is the glycol cooling system, which is mounted on the support trailer. This system interfaces with the scrub solution and extracts the thermal energy that builds up in the off-gas treatment system from cooling the combustion gases from the hood. The heat is rejected to the atmosphere is a fin tube, air-cooled heat exchanger. This makes the entire process system self-sufficient in terms of site services,



Figure 3 Process Trailers for the Large-Scale In Situ Vitrification Unit

except for electrical supply. In cases where electrical supply is remote and costly to bring in, diesel generators can be used to supply the required electricity. Details of the large-scale process equipment and the process capabilities are found in Buelt and Carter.²

The normal processing rate for the large-scale system is 3 to 5 tons/hr or nominally 3 to 5 yds³/hr, a rate competitive with many other remediation technologies. The average processing operation lasts about 150 to 200 hours depending upon the depth and electrode spacing, although for processing to depths of 50 ft, single processing operations can run in the range of 300 to 400 hours. The production rate will remain constant at 3 to 5 tons during the entire time period, resulting in a vitrified mass greater than 1,000 tons.

For routine operations on a site, all three trailers are coupled together and moved from one processing position to another by pulling them as a unit. The hood is moved from one position to another with a crane. The crane also is used to assist in coupling and uncoupling the off-gas lines. Moving from one processing position to another takes about 16 hours; thus, a relatively high operating efficiency can be achieved. This 16-hour interim for movement also provides time for performing routine maintenance.

PRODUCT CHARACTERISTICS

The ability of the waste form to retain the encapsulated or incorporated heavy metals is of prime importance to the usefulness of the ISV process.

The vitrified waste form has been subjected to a variety of leach tests, including the U.S. EPA's Extraction Procedure Toxicity Test (EP Tox) and Toxic Characteristics Leach Test (TCLP). All of these tests show a uniformly low leach rate for heavy metals of about 5×10^{-5} g/cm²/day or lower. Based on limited tests, it is reasonable to assume that the vitrified material can be delisted under the provisions of either the EP Tox or the TCLP.

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.⁴ In the natural environment, obsidian has a hydration rate constant of 1 to $20 \ \mu m^2 / 1000$ years.⁵ Using a hydration rate of $10 \ \mu m^2$ and a linear rate produces a highly conservative estimate of a I mm hydrated depth for the ISV waste form over a 10,000-year time span.

Data for the release of sodium from vitrified Hanford soil during a leach test at 90 °C are available¹ for durations of 7, 14 and 28 days. Because the sodium is soluble in the leachate, its normalized release is a measure of the extent of hydration of the glass and, in particular, its normalized release divided by the density of the glass is the depth of hydration. If the glass is assumed to hydrate according to the same parabolic rate law as has been found for obsidian, then the square of the depth of hydration divided by the duration of the test should be constant. Using the data in Oma *et al.*,¹ the result of this calculation increases between the 7- and 14-day data but is constant between the 14- and 28-day data. Taking this final value and using the density of the glass, the hydration rate at 90 °C appears to be about 2 μ m²/yr.

In the literature on field studies of obsidian hydration, the rate is found to obey an Arrhenius relation with an activation energy of 20 kcal/mole. Applying this to the ISV glass hydration, we can predict rates of $5 \mu m^2/1000$ yr at 20 °C (e.g., for glass exposed to the air) and $1 \mu m^2/1000$ yr at 10 °C (e.g., for glass buried underground). These values are comparable to those found for obsidian hydration rates in the field for similar average weathering temperatures.

The long-term stability of obsidian in nature is controlled by three mechanisms:⁴ alteration (weathering), devitrification (recrystalization) and hydration (water absorption). Review of the literature indicates that the usual controlling mechanism is devitrification. Studies of the mean age of natural glasses indicate that obsidian has a mean life of about 18 million years.⁴ Considering the similarity of the ISV waste form to obsidian, it is reasonable to postulate that the mean life of the vitrified material would be on the order of 1 million years.

The ISV waste form is a glass with the atomic structure that is random, rather than the highly structured nature of a crystalline material. This leads to another benefit: that the fracture mechanism is conchoidal, which means that the waste form is not subject to significant damage by freeze/thaw mechanisms that can accelerate natural degradation. Accelerated fracturing by a freezing and thawing would increase the surface area and the amount of material that could be leached into groundwater.

ECONOMIC ANALYSIS

The economics of the process have been examined under various conditions that represent typical conditions that might be encountered throughout the United States. While the methodology for developing ISV cost estimates was developed and reported¹ prior to the design, fabrication and testing of the largescale system, the approach is still considered valid. The two key assumptions in the initial economic projections were: (1) that the system could be operated with two people per shift, and (2) that the system could be moved from one processing area to another processing area in less than 24 hours. Both of these assumptions have been proven correct.²

Highlights of the cost estimate technique used for the initial cost projections are summarized here; details can be obtained from the original reference.¹ The cost estimate is divided into five main categories: (1) site costs, (2) equipment costs or capital recovery, (3) operations and labor, (4) electrode costs and (5) electrical costs. The two factors that most significantly affect total cost are the amount of moisture in the soil and the cost of electricity. The amount of moisture directly affects operational time and, therefore, has a direct bearing on the labor and operations costs. The electrical energy equivalent of the heat of vaporization for the moisture in the soil must be supplied and the water boiled off before vitrification can proceed.

The cost of electrical power also has a direct effect on the operational costs. Equipment or capital recovery costs and electrode costs are significant; however, they are treated as constants. Site costs are based on nominal amounts of civil work that must be performed, which include acquiring and placing clean backfill in the subsidence zone.

Equipment costs or capital recovery include the costs of the ISV system and the necessary support equipment such as a front loader and crane for earth-moving operations and moving the hood and trailers, respectively. There is also a nominal allowance for extending existing power lines and installing a substation. All equipment is assumed to have a 10-year life. The sum of the equipment costs is multiplied by a 20% capital recovery factor and added in as a unitized cost factor.

Operations and labor costs consist of the labor and materials for those activities that must be performed to support normal operations. These activities include labor time for the two operators required to operate the system. System operation is calculated on the basis of 24-hour continuous operations. Other support activities include digging the holes and placing the electrodes, moving the trailers and hood from one processing position to another and performing routine maintenance operations when the system is being moved. Also included are costs for placing the starter material and connecting, disconnecting and testing the electrodes. The operational cost also includes an allowance for secondary waste disposal, i.e., treating and/or disposing the scrub solution once per week.

Electrode costs are for the purchase of electrode materials, which are used only once, assuming that the electrodes are left in the melt. For operations in a chemically hazardous environment, the electrodes can be retrieved and sold for salvage value, which is about 20% of the original cost. For operations with a process sludge where significant decomposition of the sludge occurs, there is a potential for electrode reuse; however, estimating electrode recovery values that are higher than the salvage value is not conservative planning at this time.

These cost factors have been calculated and plotted in graphical form in Fig. 4. The maximum cost for all three cases is \$8.25/kWhr. At local electrical rates that are higher than this value, the use of portable diesel generator power is recommended. Whether the units are rented or purchased depends on the length of the remediation operation and business decisions regarding future operations. The flat rate also can be used for planning for sites where local electrical power is unavailable and bringing in a power



Figure 4 Cost of ISV Applications

line would be very expensive. The case for process sludges was included to cover those situations where the sludge has a natural radioactive component (such as radon) that must be immobilized.

PROCESS PERFORMANCE

The discussion on process performance is divided into two sections: (1) experience with hazardous wastes and (2) applications considerations. The discussion will focus on the overall treatment efficiency; the retention and/or destruction in the melt and the capture and removal of the material released from the melt by the off-gas system. The sum of the two functions represents the overall system Destruction Removal Efficiency (DRE). The results of the process performance testing with hazardous materials are subdivided into two categories: metals and organics.

Metals

During the processing operations with ISV, metals are either dissolved in the glass or incorporated in the vitreous matrix. The three factors that have the largest effect on retention are burial depth, solubility and vapor pressure. Burial depth has a direct function on retention, increasing the amount of retention with increased burial depth. Metals are retained in the melt as a direct function of the solubility and inversely proportional to their vapor pressure.

The measure of the material retained in the melt is the retention factor, defined as:

Retention Factor =
$$FR = [A]i/[A]e$$
 (1)

where [A]i is the concentration of the element A initially present and [A]e is the concentration of element A exiting the component. This terminology is used for the retention in the melt as well as the retention in the off-gas treatment system. The retention factor is the inverse of the quantity [1-DRE].

The effect of burial depth on retention of elements can be seen in Fig. 5. In these pilot-scale tests, the metals were in common chemical forms such as nitrates, fluorides and oxides. Fig. 6 shows the results of the engineering-scale tests with lead and cadmium. The lead shows a constantly higher retention in the melt with increasing depth, most likely reflecting the high solubility of lead in glass. Cadmium, which is less soluble in glass, also shows a depth-dependent retention. When estimating retention factors for metals in the melt or off-gas system, it is important to consider the solubility of the metal in the glass and also the likely oxidation state. The melt is reducing in nature, so the most likely form of most metals is either the pure state or the lowest oxidation state that will accommodate a stable oxide.





Figure 6 Element Retention vs. Burial Depth During Engineering-Scale Tests

Data from other glass processes, such as melters, are not considered reliable sources in estimating retention factors because of the difference in reducing conditions in the glass. Ruthenium in an oxidizing environment can form RuO_3 which sublimes at about 1000 °C and cause serious problems in melter off-gas treatment systems. In the pilot-scale radioactive test, ruthenium exhibited a retention of 99.82% or a decontamination factor (DF) of 550. The enhanced retention because of oxidation state and solubility is very important when assessing potential applications to traditionally volatile metals.

Retention factors measured in pilot-scale testing are shown for both the melt and the off-gas treatment system in Table 2. These data allow one to predict the retention of other hazardous metals. Results for large-scale testing show that retention continues to increase with increasing depth below 1 m. An order of magnitude increase in retention was observed when the depth was increased from 1 to 5 m.² The presence of combustibles can provide a path to the surface by entraining the metals in the combustion product or pyrolytic gases, increasing the retention fraction. The closer to the surface, the more likely the entrained material will not be scrubbed out by the molten glass and recaptured. Even the decomposition of nitrates can provide an elution path if the reaction occurs nears the surface.

Enhanced releases associated with combustion events are shown in Fig. 7. These results are also from pilot-scale tests where the simulated metals were deliberately placed with combustibles. At each combustion event, the concentration of the metals in the scrub solution increases measurably with a clear change in the slope of the concentrative curve.

	Table 2		
Retention	Factors	of	Metals

Type of Metal	Soil	Off-Gas	Combination
Particulates			
Sr, Pu, U, La, Nd	105	105	1010
Semi-Volatiles			
Co, Cs, Sb, Te, Mo	10 ²	104	106
Volatiles			
Cd, Pb	2-10	104	105
•=,=			

These data are important for estimating the amount of secondary waste that will be generated by contaminating the scrub solution with hazardous chemicals, necessitating potential treatment of the scrub solution before its disposal. With a meter of clean overburden, decontamination factors (DFs) of at least 100 can be expected even for the volatile elements. Decontamination factors of 1,000 and greater can be expected for the semi- and nonvolatile metals, assuming that there is no significant quantity of combustibles.



Figure 7 Cadmium and Lead Release as a Function of Run Time

Organics

During processing, organics that are contacted by the vitrified material are destroyed by pyrolysis. The pyrolytic gases move upward through the melt and combust when contacted by the oxygen atmosphere in the hood. The data base for processing organics has been limited to selected organics in containers, PCBs and organics associated with electroplating wastes. As the ISV process gains additional acceptance as a remediation tool, the data base will grow.

Combustible testing with organics has included up to 50 kg of solid combustibles and 23 kg of liquid organic in a single pilotscale experiment. The materials were packaged in a container such as might be found in a solid-waste burial ground. Chromatographic, sample bomb and mass spectrometric analyses of the effluent from both the hood and the exhaust stack showed less than 5×10^{-3} vol% release for light hydrocarbons during peak combustion periods. This level of release indicates nearly complete pyrolysis and combustion.⁶

A limited number of experiments have been conducted to define the pressure rise and rate of release associated with organics in sealed containers. Theoretical calculations predicted that the internal pressures would be several hundred lb/in.², and that the pyrolized material would produce a transient pressure wave that would move through the melt in a few seconds. The tests were performed using the engineering-scale system; the sealed containers were lecture bottles, equipped with pressure sensors. The maximum pressure observed was 32 lb/in.2; the pressure attenuated over a period of 1.5 min. These data indicate that the metal softened as the vitrified zone approached the sealed container, and that the intrusion of the glass was slower than the theoretical maximum rate. This could be a scaling effect, related to the relatively high viscosity of the glass. Intrusion into a buried 55-gal drum is expected to be very rapid. The organics in the containers were completely destroyed.

An engineering-scale test was conducted using soils contaminated with 500 ppm of PCBs. The data from the test showed that the process destruction was slightly greater than 99.9%. The small amount of material released to the off-gas system was effectively removed, yielding an overall system DRE of > 99.9999%. Analysis of the vitrified block showed that there were no residual PCBs; considering the processing temperature, the data are reasonable. The soil adjacent to the vitrified area was examined for PCBs; limited quantities were detected (0.7 ppm of PCBs). These data indicate that the vitrification rate is greater than the PCB diffusion rate and that migration away from the vitrification zone during processing is not a significant concern.

Engineering-scale tests on electroplating wastes have shown that the destruction efficiency for contaminated soils is $\geq 97\%$ for the process even when the contaminated soil is not covered with a layer of clean soil. Other tests have shown that an uncontaminated layer of soil increases the efficiency of the process to greater than 99.99%. Additional removal can be obtained by the use of charcoal filters in the off-gas treatment system, thus improving the overall system DRE.

The observed system DREs indicate that the process has a potential to be a very valuable tool for the remediation of sites that contain both organic and metallic hazardous wastes. While the results are promising, feasibility testing to confirm applicability is strongly recommended prior to any commitment to deploy the process on a site that contains significant quantities of organics that are unconfined in the soil column.

APPLICATIONS CONSIDERATIONS

Prior to exploring various hazardous waste application scenarios, the operational capabilities and limitations of the largescale system will be reviewed. The capabilities of the large-scale system to treat various soil characteristics and inclusions can logically be divided into two categories: (1) capabilities of the power supply system and (2) capabilities of the off-gas system to maintain a negative pressure during transient events. The capabilities of the electrical system in terms of electrode width, depth and shape have been reported in Oma *et al.*¹ and Buelt and Carter.²

The two factors that can influence the ability of the power supply system are the presence of groundwater and buried metals. As a general rule, soils having low permeabilities do not inhibit the ISV process even in the water table because the rate of recharge is not significant in terms of the processing rate. The melt proceeds at a rate of about 3 to 6 in./hr. Thus, soils with permeabilities in the range of 10^{-5} to 10^{-9} are considered able to be vitrified even in the presence of groundwater or in the water table. Soils with permeabilities in the range of 10^{-5} to 10^{-4} are considered marginal. Soils with permeabilities higher than 10^{-4} are difficult to vitrify in the water table unless additional steps are taken, such as drawing the local water table down by pumping and installing underground barriers.

The presence of buried metals can result in a conduction path that would lead to electrical shorting between the electrodes; however, the processing margins are quite generous. Buried metals that occupy up to 90% of the linear distance between the electrodes can be accommodated without suppressing the voltage between the electrodes. Also, once melted, the impact of the metal is less significant. Miscellaneous buried metal, such as drums, should have little or no effect on the ability to process a candidate site. Metal limits are currently 5 wt% of the melt. This is a large fraction when considering drums of waste. In fact, drums containing hazardous and/or classified wastes can be placed in an array that will take advantage of the melt configuration. Such an array is shown in Fig. 8. Here, the metal content of the 273 drums is 1.5% of the melt weight, leaving considerable capacity for miscellaneous metal contained within the drums.

ACCEPTABLE CONDITIONS 90% LINEAR DISTANCE & 5 w1%



METAL WI - 1 5% OF MELT MASS



Capacity of the off-gas system to maintain a negative pressure during processing, thus preventing the spread of contamination or resulting in fugitive emissions, is a function of the gas generation rate within the processing area. Gas generation resulting from the decomposition of humus and other natural chemicals within the soil is considered insignificant. Gas generating situations are generically shown in Fig. 9. These represent the intrusions of the molten glass into void spaces. Such intrusions result in release of the entrapped air, penetration of a drum that contains combustible materials and intrusion into soil inclusions that contain combustible materials, either solids or liquids.

Large-Scale Designed to Contain Rapid Gas Releases



Figure 9 Gas-Generating Configurations

Schematically, the capacity of the off-gas system to contain the gas resulting from the processing event is shown in Fig. 10. These capacities are representative of what might be encountered in a solid-waste burial ground. The release of the gas is a transient event, ending in about 1 minute. Therefore, once the transient event has passed, the system still has the capacity to handle another transient event. These are time-order limits, not cumulative capacities.



Figure 10 Combustible Limits for ISV Processing

The ISV process is particularly well suited to in-place disposal of hazardous waste. The toxic heavy metals are encapsulated or incorporated into the glass, and the organics in containers are destroyed. Certain inorganic compounds such as nitrates also are destroyed by reducing the compound to the diatomic gases by the temperature and reducing conditions of the melt. Sulfates are partially decomposed; the remainder can easily be removed by the off-gas treatment system. Fluorides are dissolved into the glass to 98% for source terms of several hundred ppm. Chlorides are dissolved to the limits of solubility, which are much less than those for fluorides, but up to 1 wt% of the melt, which can be a large quantity. The fluorides and chlorides not dissolved in the glass can be scrubbed out by the off-gas treatment system, using a caustic scrub solution.

There are five general areas where the ISV process might be applied to mixed hazardous waste: (1) contaminated soil sites, (2) burial grounds, (3) tanks that contain a hazardous heel in the form of either a sludge or salt cake, (4) classified waste that is already containerized or amendable to containerization and (5) process sludges and tailings piles that contain radioactive materials. The application of the ISV process to contaminated soil sites and burial grounds is similar to the previously discussed application to general soil and burial ground sites, with the same processing limits for metal and combustibles.

The use of ISV to destroy the hazardous heel in tanks has been tested on the engineering scale with chemical salts. The results of the feasibility study showed that the release was within acceptable limits for the off-gas system and that a vitreous mass was formed. The original tests were performed adding glass formers during the processing to achieve a vitreous waste form. The data could be extended to the disposal of the residual heels and the tank and to immobilize contaminated soil in the immediate vicinity of the tank.

By adding soil and/or rock backfill, the tank could be filled with glass-forming materials prior to processing. This could eliminate the concerns of tank dome and/or wall collapse identified during the original testing. Techniques for filling to the peak of the tank dome have been developed. Electrodes would be inserted into the tank through existing openings. The vitreous area would grow downward and outward, encompassing the tank, the contents and a portion of the surrounding soil. Estimates of the maximum size tank have not been completed, but tanks in the range of 100,000 to 300,000 gal could be permanently disposed by this technique. The metal content of the tank structure should not impose a processing limit.

Process sludges and tailing piles that contain natural radioactive materials and hazardous chemicals can be disposed using the ISV process. Applications that involve natural radioactive elements that result in relatively high radon fluxes at the surface are considered potential candidates for remediation by ISV. Tests with zirconia-lime sludges showed that the material was not only able to be vitrified, but that the radon emanation level was reduced by a factor of 104 to 10⁵ after processing. Measured radon emanation rates were in the femto curie range. This is a practical solution where the radon emanation levels are high, the wastes also contain hazardous chemicals that could be leached into the groundwater and the local infiltration rate is high. In contrast, for large piles in remote areas and where the infiltration rate is very low, barriers over the pile have quite effectively prevented release of hazardous chemicals. Each potential application must be examined on its own merit.

Valuable land that is contaminated can be reclaimed by the use of ISV processing, converting a corporate liability to a capital asset. Old transformer areas and capacitator storage and repair areas that are now in the business district, but contaminated with PCBs, are examples of this concept. The ISV process has been effective on PCB-contaminated soils, achieving a system destruction removal efficiency (DRE) of 99.9999%. There will be some limitations associated with equipment access; however, these usually can be dealt with by a combination of equipment design and staging operations.

Other applications considered, but not yet developed, include shaft sealing, foundations and erosion barriers for remote locations and the generation of impermeable barrier walls to prevent groundwater seepage into a site. Barrier generation is considered an interim solution that would mitigate an existing hazardous situation until a final solution could be implemented.

PROCESS STATUS AND BENEFITS OF APPLICATION

The ISV process has been demonstrated at field-scale conditions, thus eliminating the risks of scale-up. This is significant because scale-up is the major risk area in the development and deployment of a new technology. Technology adaptation is a much smaller investment risk than technology development. The applicability of the ISV process to a particular waste can be determined with existing ISV equipment for a few thousand dollars. Thus, feasibility testing is relatively inexpensive. The focus of the feasibility testing is the performance requirements for the off-gas treatment system and the type and quantity of secondary waste generated. It has already been shown that almost all of the soils encountered are able to be vitrified, so this is not a consideration during most feasibility testing.

The experience to date indicates that the process is ready for deployment for soil sites contaminated with heavy metals and inorganics. Experience with low boiling point organics that are uncontaminated in the soil column is very limited, and feasibility testing with actual site samples prior to application is strongly recommended. The experience with PCBs, process sludges and plating wastes is very encouraging. It is anticipated that the ISV process will be used for a broader application of waste management problems. It is also recognized that no single treatment process is applicable to all waste management needs. Within this context, ISV is a new and powerful tool that should be considered and evaluated for radioactive, mixed hazardous and hazardous chemical applications that fall within the treatment capabilities of the process.

Specific benefits inherent in the ISV process are:

- Safety for workers and public
- Long-term durability of the waste form (>1 million years)
- Applicability to a variety of soils
- Cost effectiveness (\$100-\$250/ton for soils)
- Volume reduction for sludges (<\$100/ton)
- Efficient processing rates (3-5 tons/hr)

The safety aspect includes both containment during processing, as well as the lack of potential transportation accidents that might be involved with exhumation and off-site shipment of the waste. The durability of the waste form is consistent with the potential length of the foreseen hazards associated with both radioactive and chemically hazardous materials. The projected stability of more than 1 million years for the life of the waste form is consistent with the hazard of even long-lived radioactive isotopes, such as plutonium. While it might be argued that heavy metals have no half lives, the waste form life is consistent with prudent environmental planning.

In summary, the applicability of the ISV process to a wide variety of soils and wastes, combined with the process' costeffectiveness, are responsive to the regulatory changes that are currently in progress, i.e., changes which emphasize the need for on-site treatment and remediation as opposed to off-site disposal.

ACKNOWLEDGEMENT

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Aquifer Restoration via Accelerated In Situ Biodegradation of Organic Contaminants

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ABSTRACT

Recovery of the appreciable quantities of free floating hydrocarbons has become a proven reliable technology for minimizing the spread or impact from subsurface hydrocarbon losses. Retrieval of the free floating phase does not, however, mitigate all the associated impacts, nor does it return the aquifer use or potential use. Hence, cleanup and restoration to natural conditions through accelerated in situ aerobic degradation of organics by native hydrocarbon utilizing bacteria is a cost-effective alternative.

Subsurface contamination from hydrocarbons predominantly exists in the three phases of free floating of mobile hydrocarbons, product adsorbed onto the soil matrix and hydrocarbons dissolved in the aqueous environment.

The latter two phases of adsorbed and dissolved hydrocarbon contamination affect a greater area within the formation. The symptomatic impacts, although less intense than free product, are more persistent.

This paper discusses a 3-year abatement program implemented to address hydrocarbons adsorbed/dissolved into the groundwater system. The treatment program consisted of a combined physical/chemical/biodegradational approach to reduce aquifer degradation and supply potable interim portable water to the impacted well owners.

The in situ biodegradation phase consisted of: (1) introduction of clean oxygenated water from beyond the contaminated plume, (2) addition of dissolved oxygen by mechanical air spargers, (3) utilization of hydrogen peroxide to supply dissolved oxygen and subsequent phase out of air spargers and (4) addition of nutrients at prescribed doses and intervals. The net results of the work program are a 70%-80% reduction of total hydrocarbons within the aquifer.

INTRODUCTION

Many of the organic compounds which were developed in the late 1920s and 1930s to serve the needs of evolving technological societies have found their way into the environment. These compounds originally developed to serve mankind have become a nemesis. The increasing awareness of soil and groundwater degradation by organic compounds is now widely recognized as a problem of international dimension. The sources and vehicles for the entry of these diverse compounds into the soil and groundwater system are as varied as the contaminants.

Historically, deliberate and sometimes sanctioned disposal of waste solvents, sludges and off spec products into landfills have resulted in significant environmental degradation. Today, an even more common, yet equally unintentional, source of loss of organic chemicals to the soil and groundwater system presents itself in the form of leakage from below ground transmission lines and tanks used to contain these compounds. This paper discusses one such problem of soil and groundwater degradation by benzene, toluene, xylene and certain associated inorganic parameters in terms of its treatment and abatement.

The key to the treatment and abatement of this particular cleanup is the application of an in situ bioreclamation technique which enhances the growth of existing native hydrocarbon-utilizing bacteria by means of the addition of nutrients and oxygen to the groundwater system. This paper presents information showing the superiority of oxygen transmission to the groundwater system through the use of dilute mixes of hydrogen peroxide over traditional mechanical air spargers.

The aquifer cleanup and abatement program also incorporates a comprehensive physical-chemical treatment system for water neutralization and metallic compound removal.

BACKGROUND

In this case history, the contamination problem occurred when an undetermined amount of gasoline leaked from a below ground storage tank. The area of the loss is underlain by approximately 6 to 7 ft of red-brown, heavy silt loam which, in turn, is underlain by a fractured red-brown shale and silt stone. The groundwater table is found within the bedrock system at a depth to 20 to 25 ft below grade. The gasoline migrated through the overburden into the bedrock groundwater system.

The resulting significant impacts of the loss included soil contamination by absorbed concentrations of gasoline-type hydrocarbons which proved to be a continuing source of organic vapors and contamination source of low level water-soluble organic compounds to groundwater. Associated changes in geochemistry also led to increased concentrations of iron and manganese. The re-



Figure 1 Typical Impacts from Loss of Organic Chemicals

sulting impacts affected the quality and use of 10 domestic water supply wells. The observed impacts were typical of leaks of such materials, except a free floating phase was absent (Fig. 1).



(Data Taken from Groundwater Technology Monitoring Wells)



Figure 3 Isocon Map of Initial Hydrocarbon Contamination (ppm) of Domestic Wells



Figure 3B Isocon Map Iron Concentration (ppm) (November 1981)

PROBLEM ASSESSMENT

The areal extent and magnitude of the organic contamination was determined via a combined program of sampling and analysis of domestic wells and the installation of 12 additional observation wells.

The data showed a plume of dissolved organics and inorganics

that extended approximately 200 to 250 ft in a north-south direction and 300 to 350 ft in an east-west direction. The east-west plume elongation proved a function of local geologic structure and direction of groundwater movement (Fig. 2 and 3). Contaminant concentrations ranged from less than the detection limit (10 $\mu g/l$) to greater than 15 mg/l for gasoline type hydrocarbons. Iron and manganese concentrations ranged from 0.1 mg/l to 6.7 mg/l and 0.2 mg/l to 12.0 mg/l, respectively (Fig. 3A and 3B).

DEVELOPMENT OF CONTAMINANT ABATEMENT PROGRAM

As the organic/inorganic contamination was spread through a significant portion of the aquifer, a comprehensive aquifer restoration program was required to restore the groundwater to usable quality. The cleanup was directed at the organic compounds, as they were deemed the most unacceptable in the drinking water supply. The presence of the organic compounds and subsequent changes in aquifer geochemistry also appeared responsible for the increased leaching and presence in drinking water of the two trace metals. The program developed was based on both field and laboratory bacterial cultures (*Nocardia* and *Pseudomonas*) that were hosting and degrading the organic compounds present. Studies further indicated that the greatest limitations on the rate of degradation by the aerobic bacteria were the amounts of oxygen and certain inorganic nutrients.

A system of contaminant plume and water table manipulation via pumping, dissolved organic removal of the pumped water by air stripping and accelerated in situ biodegradation of adsorbed dissolved phases by physical addition of oxygen and nutrients was designed (Fig. 4).



Figure 4 Schematic of Bioreclamation System

Prior to operation of the system for aquifer restoration and removal of the organics, it was necessary to develop a means of supplying the impacted residents with aesthetically usable water beyond their bottled water supply.

Further chemical analysis, beyond organic scans, showed a need to address both inorganic and organic compounds. The analytical results dictated the development of a physical/chemical treatment process that relied on neutralization, carbon adsorption, ion exchange and biological treatment (Fig. 5). This combination of treatment steps produced aesthetically usable water, which was free of any residual dissolved organic compounds.



Notes:

1. Neutralizing filter; preliminary sediment, iron and manganese removal.

- 2-2a. Taste and odor filter; activated charcoal with high surface area for removal of taste and odor (removal of hydrocarbons).
- 3. Portable ion exchange units (in parallel); removal of hardness and further iron and manganese removal.
- 4. Ultra violet light; bacteriological treatment unit for coliform treatment.

Figure 5

Schematic: Water Treatment System to Improve Aesthetic Water Quality in Residences Affected by Suspect Hydrocarbon Contamination

INITIATION OF ABATEMENT/ AQUIFER RESTORATION

In implementing the designed program, the practical approach adopted took into account the nature of the problem, the source, the configuration of the plume, the nature of the groundwater system and the character of the community. The program development was carried out in a logical sequence which included:

- Development, installation and shakedown testing of the physical/chemical water treatment system on domestic wells
- Excavation and disposal of highly contaminated soil in the tank pit area
- Conversion of the tank pit, via backfill with crushed stone, to an infiltration gallery
- Construction of a pumping well located in the center of the plume to control the water table and movement of contaminated groundwater
- Pump testing of the central well to allow calculations of the expected radius of influence to assess the well's capability to control the migration of the plume
- Construction and erection of an air stripper for volatile organic removal
- Development of nutrient mix ratios for addition to the groundwater system to accelerate hydrocarbon-utilizing bacteria for reduction of the fugitive organics
- Development of mechanical means of air supply and air sparging to deliver oxygen into the groundwater system; previously existing observation wells were used as air sparging and nutrient addition points
- Development and construction of a nutrient mix tank in the area of the infiltration gallery for batch feed of nutrients to the contaminated tank pit area
- Shakedown testing of the system to ensure operational efficiency in the control of the organic plume

The system, as designed, was to begin pumping at the central well, inducing water in the plume to flow radially inward from the periphery. The recovered contaminated water was then to be passed through an air stripping tower where volatile organics were to be removed and oxygen was to be added. Nutrients were then to be added to the hydrocarbon-free/oxygen-rich water, which was then to flow through the contaminated soils and groundwater system, thus accelerating the in situ reduction of organic compounds via the increased numbers of hydrocarbon-utilizing bacteria.

The control of the spread of nutrients, oxygen and microorganisms was to be maintained by the central pumping well. The treatment for the organics was to be enhanced via the addition of oxygen and nutrients on the periphery of the plume. This water was then to be pulled back through the contaminated zone to the central plumbing well.

RESULTS OF THE ABATEMENT PROGRAM

The results of the aquifer restoration program were quite good. The physical/chemical treatment system for the domestic wells functioned well, producing a reliably usable water supply (Fig. 5A and 5B). As the total aquifer cleanup program moved forward, decreased frequency of treatment media exchange (i.e.,



Figure 5A Manganese Concentration Pre & Post Physical-Chemical Treatment



Iron Concentrations Pre & Post Physical-Chemical Treatment

activated carbon) was required, thus attesting to overall contaminant reduction. The central pumping well contained and controlled the plume configuration like an in situ treatment vessel (Fig. 6). The air stripping tower, subsequent to shakedown testing, performed as designed with greater than 98% to 99% efficiency for removal of volatile organics (Fig. 7). The designed infiltration gallery, located in the former tank pit, proved functional in accepting the 30,000 to 35,000 gal/day of treated oxygen- and nutrient-rich water. Heavy spring rains and recharge caused some concern regarding overtopping of the gallery which, however, did not occur.

The air sparging system, consisting of mechanical air compressors, air lines and down well diffusers, proved to be effective to partially effective in delivering needed oxygen to peripheral areas of the plume outside the infiltration gallery. The major limitations were the maximum quantity of oxygen that could be induced into the groundwater system (10 mg/l) at the sparging point and the fouling/plugging of the sparging points by the development of thick biological growths. These two items precluded optimum oxygen transfer to the fractured bedrock system and required frequent mechanical cleaning.

Despite non-optimum conditions, cleanup over the first 11 months resulted in a 50% to 85% reduction in organic contaminants. Several wells had no organic contaminants at this point (Fig. 8 and 9).

While pleased with the overall results, the rate of oxygen transfer was limiting microorganism growth rates and lengthening the



Figure 7 Total Hydrocarbon Concentrations for Air Stripping Tower

project restoration time; therefore, a program to accelerate this problem was developed. The program involved a comprehensive approach that included:

- · Laboratory research
- Field studies
- Further hydrogeologic and engineering assessment
- Information/educational meetings and contact with representatives of the community and regulatory agencies



Total Hydrocarbon Concentrations for Core Homes

The result of the applied efforts was the development of a comprehensive approach to deliver increased quantities of oxygen to the groundwater system via the trickle feed and disassociation of dilute concentrations of hydrogen peroxide. Laboratory studies were conducted jointly by R.L. Raymond and FMC (Richard A. Brown). Use of hydrogen peroxide increased bacterial numbers and subsequently the rate of hydrocarbon reduction. Field studies by R.L. Raymond also showed similar results. In the development of the handling, delivery and application techniques for hydrogen peroxide, the experience of FMC Corporation was most valuable.

Laboratory and specific field trials at the project site showed favorable results. One specific area of the site, located in a down dip area from the origin of the contamination, proved troublesome in maintaining a sufficiently high dissolved oxygen rate to support the aerobic biodegradation of the fugitive organics. As a means of testing the new oxygen diffusion technique under worst case conditions, a 5-gal batch of peroxide at a 100 mg/l concentration was added to a point on the periphery of the plume, which was approximately 40 ft from the closest sampling location toward the pumping well. The test was initiated with the central pumping well in operation, to induce flow of water and hydrogen peroxide to it; dissolved oxygen increased from 0.5 to 8.0 mg/l in a 24-hr period. The increase in dissolved oxygen also stimulated an increase in microbiological activity and a decrease in hydrocarbon concentrations.



Figure 9 Isocon Map of Hydrocarbon Contamination (ppm) of Domestic Wells 10 Months after Start-Up

The concentration of hydrogen peroxide used in the ongoing program for enhanced bioreclamation has been 100 mg/l, yielding 50 mg/l of dissolved oxygen for uptake and utilization by the microbiological community. Hydrogen peroxide currently is being added to the groundwater system at the site, both at the infiltration gallery and former air sparging wells. An added benefit of hydrogen peroxide use in the wells is that when introduced to the well bore at 100 mg/l, it keeps the well free of heavy biogrowth, thus allowing even and quick transmission of needed oxygen to the impacted areas of the groundwater system. The most recent results from the site show that overall hydrocarbon concentration levels have declined in the core area, with only five homeowner wells still showing degradation (Fig. 10).

CONCLUSIONS

The applied techniques of physical/chemical treatment of domestic well water combined with groundwater manipulation via a pumping well, air stripping for volatile organic removal and enhanced biostimulation/bioreclamation of groundwater systems contaminated by organic compounds proved a most applicable and cost-effective technique. Limitations of oxygen transfer critical to aerobic decomposition of the organic contaminants can be overcome by the application of a superior oxygen donor, such as hydrogen peroxide.

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Figure 10 Isocon Map of Hydrocarbon Contamination (ppm) of Domestic Wells (After Hydrogen Peroxide Addition)

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Operation of a Light Hydrocarbon Recovery System: Theory, Practical Approach and Case History

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ABSTRACT

Light hydrocarbon recovery systems can have a wide range of recovery well designs and equipment arrangements to meet an equally large variety of geologic situations. However, the principles of operation and data management for all recovery systems are simple and easy to apply to all situations and equipment configurations. The piezometric surface is determined for the water and free hydrocarbons in the monitor wells. This surface is then systematically controlled to prevent the further spread of liability and to recover the free hydrocarbons. The determination of the piezometric surface and its use as the control surface automatically compensates for unknown factors such as the permeability of the soil with respect to the hydrocarbon, relative flow velocities and volume of material spilled.

INTRODUCTION

The purpose of a gasoline recovery system is to limit the exposure to liability and remove the gasoline from the subsurface. The conditions under which this is achieved vary with each site; however, several general conditions are present in all cases.

Gravity is the driving force that causes the gasoline to spread out on the surface of the water table, and gravity is the only force used to collect the gasoline when the recovery system is implemented. The conditions that influence the spread of the plume are the permeability of the soils with respect to gasoline and the shape of the water table surface.

If the water table is flat and groundwater flow velocities are low, the gasoline will spread in all directions with a slight bias toward the direction in which the groundwater is moving. If the water table has a steep slope and groundwater velocities are high, then the plume will stream out in the direction of groundwater flow unless there is a large difference between the permeability of the soils with respect to water and gasoline.

To achieve its purpose, a gasoline recovery system must influence the shape of the water table enough to stop the spread of the plume and direct the flow of gasoline to a location where it can be pumped out of the ground. This process is accomplished by pumping a well sufficiently fast to create a cone of depression. Once this cone of depression is created, the gasoline will accumulate in the depression wells and can be removed from the ground. As the plume gets smaller, the depression level is raised in stages until finally there is no gasoline accumulating in the well and the monitor wells show only a sheen or no gasoline at all. After the system is turned off, monitoring continues for a quarter. If at the end of that time no new accumulation of gasoline is found, then the recovery system has done its job.

RECOVERY WELL LOCATION

Determining the location of the recovery well is relatively easy

if there are enough monitor wells to define the extent of the plume and the groundwater gradient. The purpose of the recovery well is to create a hydraulic barrier that will prevent the further spread of the free hydrocarbon plume and collect the hydrocarbons for removal from the subsurface. The hydraulic barrier can be produced by one well drawing the water table way down or by multiple wells with each providing a small cone of depression and thus collectively creating a hydraulic barrier. Since the purpose of the recovery well is to control the movement of hydrocarbons floating on the water table rather than to produce a large volume of water, multiple wells or a trench collector system are preferable to a single well in controlling large plumes.

Multiple well systems have the disadvantage of requiring pumps, piping, electrical connections and pump controllers for each well. This duplication of equipment is very expensive to install and adds to the operation and maintenance costs. Storage tanks for the hydrocarbons may be fed by more than one well, and water from multiple wells can be treated in one system. To avoid excessive costs, a collector trench with one or more sumps is preferred over multiple well systems. The installation of the collector trench generally is not practical where the water table is deeper than about 8 ft below land surface. In order to create a hydraulic barrier, the depression level must be several feet below the normal water table. If the water table is 8 feet deep, then the trench has to be 12 ft deep and the sump where the pumps are installed has to be several feet deeper than the trench.

The location of the well, wells or trench should be on the downgradient side of the plume where the monitor well data indicate the presence of the greatest amount of hydrocarbons. The hydraulic barrier must have a wide enough area of influence to reverse the flow of hydrocarbons that lie on the downgradient side of the barrier.

STAGES OF OPERATION OF THE RECOVERY WELL

The critical factor in the operation of the recovery well is maintaining the hydraulic barrier. Hydrocarbon removal is a secondary factor. By maintaining the hydraulic barrier, the plume is controlled so that there is no increase in liability. Maintaining the hydraulic barrier causes the soils to dewater, thus improving their permeability with respect to hydrocarbons and improving the rate at which they will flow to the recovery well. Experience has shown that the rate of hydrocarbon accumulation in the recovery well is often greatest in the dryest months of the year. When the soils are dry, the permeability with respect to hydrocarbons increases dramatically. The recovery operation in areas where rainfall is relatively constant throughout the year may take longer than in areas where there are strong seasonal differences in soil moisture content. Fig. 1 illustrates the stages of operation of a recovery well. The initial depression level in the recovery well is set so that the cone of depression controls the edge of the plume. The initial depression level has two immediate effects: first, the migration of the plume is controlled and second, the hydrocarbons that were on the water table surface are now migrating downward in the partially saturated soils above the new water table surface. In Fig. 1, hydrocarbons that were at point "A" prior to turning the depression pump on must travel to point "B" before resuming their migration can take from several days to weeks. During this re-equilibration period there often is little or no hydrocarbon accumulation in the recovery well, and the installation can appear to be a failure.



Figure 1 Stages of Recovery Well Operation

As the plume diminishes in lateral extent, the depression level may be raised in the recovery well as illustrated in Fig. 1. The depression level should be raised cautiously. If it is raised too quickly, there may be a loss of plume control, and the recovery well will no longer limit one's liability. If plume control is lost, then the lower depression level will have to be used again and, in essence, the recovery operation will start from the beginning. Having a large number of monitor wells can prevent such errors that cost far more than the cost of a few monitor wells.

As the plume continues to diminish, the depression level can be raised until the free hydrocarbons no longer accumulate in the recovery well and the cleanup is complete. The depth of the initial depression level and the number of times the depression level is raised are decisions that must be made for each site and its specific conditions. Although each site will have its own peculiarities, this approach will work under all conditions.

RECOVERY WELL EQUIPMENT

There are potentially two complete pumping systems that may be installed in a recovery well. The critical system is the groundwater depression pump and its controllers. The second system is the hydrocarbon removal system. A variety of manufacturers make complete systems, or the components can be bought separately and combined into a custom system.

Groundwater Pumping

The basic requirement is that the system is reliable. The depression pump will be required to maintain the cone of depression for at least 6 months and more likely several years before the cleanup is complete. Each pump or controller failure will result in the temporary loss of control of the plume and a return to the beginning of the recovery effort.

The depression pump should be adequately sized for the flow rate and heads resistance in the piping system. The seals and wiring in the pump should be resistant to attack by hydrocarbons. The depression pump control should be based on the hydrocarbon/water interface in the well. This interface should not get close to the pump intake to cause raw hydrocarbon to be removed with the water; therefore a second low water shutoff sensor should be installed in the well in addition to the normal depression level sensor.

The water from the depression pump must be treated and discharged in accordance with local regulations. Fig. 2 shows the components of a well designed depression pump system. A flow meter and site glass are installed in the piping from the well to allow one to monitor the recovery effort's progress. An oil/water separator tank is included in the piping system as a fail safe protection against discharging raw hydrocarbons. Discharge is from the bottom of the tank through a piping loop with an anti-siphoning vent. This loop is installed at a height that assures that if hydrocarbons are pumped to the tank, the high level shutoff will be triggered before the hydrocarbons reach a level where they will be discharged. The height of the loop is therefore dependent on the density of the hydrocarbons involved.

The least costly alternative for water disposal is to a sanitary sewer system. In this instance, the oil/water separator is very important because it prevents the discharge of raw (hydrocarbon) product to the sewer, which may result in a greater liability than the original spill. Where the recovered water is reinjected into the ground, the separator is very important as it assures that the hydrocarbons are not simply transferred from one location in the subsurface to another.

Hydrocarbon Removal

Hydrocarbons are removed by pumping or skimming the free phase of hydrocarbons off the water surface in the recovery well. This activity is almost independent of the depression pumping. The choice of manual, automatic or semiautomatic systems is available. Again, a judgment must be made as to which system is best suited for the situation. Where large volumes of gasoline are expected to flow to the well, an automatic skimmer or pump is best for the job. Automatic systems do require a complicated set of controls and sensors which require cleaning and maintenance, a holding tank for the recovered product which must meet local fire regulations and a well sized to accommodate all the pumps, lines and sensors.



Figure 2 Typical System for Handling of the Pumped Water and Hydrocarbons

Fig. 2 shows a typical arrangement for a recovery system with a skimmer in the well to remove gasoline. Such an arrangement requires a well on the order of 30 or more inches in diameter, and the skimmer has a limited pumping pressure. For both of these reasons, such systems usually are installed where the water table is less than 15 ft below the land surface. Installations where the water table is deeper use a down-hole pump for removing hydro-carbons. Again, because of the need to accommodate pumps, cables and controls for two systems, the well must be at least 10 in. in diameter.

Where the water table is deep and the amount of free gasoline is relatively small, a single pump can be used. This pump serves as the groundwater depression pump most of the time as the gasoline is allowed to accumulate in the well. When several feet of gasoline are present, the discharge from the pump is connected to a waste tank and the well is over pumped to remove all the water and gasoline. The periodic removal of gasoline will become less frequent as the plume diminishes, thus reducing operational costs.

MANAGEMENT OF THE RECOVERY PROCESS

The subsurface conditions are determined by drilling a series of monitor wells that penetrate the water table. The screen that is installed in the monitor wells must extend above the water table to allow the gasoline which moves on the water table to enter the well. Boring logs of the soils encountered while drilling the monitor wells gives an indication of the permeability of the soils and indicates whether the recovery system will use wells or trenches as the means of controlling the water table. Generally, four to seven monitor wells can be drilled in a day. The numbers and locations of the monitor wells are determined by such physical restraints as the location of buildings, overhead wires and the information provided by each borehole as it is drilled.

Unless there is strong evidence of gasoline in most of the monitor wells at the time they are drilled, they will be allowed to equilibrate for a day before fluid measurements are made. If there is strong evidence of gasoline at the time of drilling, additional drilling will be done on subsequent days to determine the gross extent of the plume. After the wells have equilibrated and the data have been analyzed, a few additional wells may be needed to complete the delineation of the plume so that the recovery well or wells can be effectively placed. The need for additional monitor wells is determined by the number of unanswered questions about the site:

- Is gasoline migrating along utility or sewer lines?
- Could there be a plume for a second source?

It is a judgment call for each situation, and one more well will never hurt.

MONITOR WELL MEASUREMENT METHODS

Water Table and Hydrocarbon Monitor

Well Measurements

The measurements are made with a transparent plastic bailer type sampler suspended on a fiberglass measuring tape. A ball check valve in the bottom of the bailer allows a sample showing the product thickness to be withdrawn from the well. Fig. 3 illustrates the measurement process. The measuring tape is attached to the lower end of the bailer and passes up through the center of the body of the bailer. This arrangement allows direct readings from the tape where it passes through the top of the product layer and at the product water interface. The length of measuring tape in the well indicates the depth of the sampler and is recorded as the "Tape Reference" as shown in Table 1. If the product layer is thicker than the length of the bailer, then deeper measurements are made until the product water interface is found. Under these circumstances, a deeper tape reference is shown for the water measurements than the product measurements.



Figure 3 Typical Monitor Well Measurement Process

 Table 1

 Water Levels and Product Thickness Readings Taken in a Monitor Well

Dirty Dunbar, Fremont, CA

	Nate	r Readi	ngs	Pro	het Rea	dings				Calcul	ated Val	ues in Faet	
-11	Tape	Tape	Nater	Tape	Tape	relect	Hell	Patua	ł	Product	Water	Piezosetric	Product
Xe.	Ref.	Read.	Bepth	Ref.	Read.	Bepth	No.	Elevation	ł	Thickness	ELev.	Elevation	ELev.
1	7.80	.43	7.37	7.90	.71	7.02	1	20.37	;	. 35	13.00	13.27	13.3
2	9.10	. 64	8.44	7.20	. 46	6.74	2	20.44	:	1.72	11.98	13.29	13.70
3	4.70	. 48	4.22	4.70	. 60	6.10	3	19.31	;	.12	13,09	13.18	13.2
- 4	7.20	. 55	4.45	7.20	.00	.00	4	20.04	:	.00	13.39	13.39	.0
5	7.40	.73	8.47	7.20	.75	6.45	5	20.38	:	2.22	11.71	13.40	13.93
•	Below a	ell bol	toe.	7.20	. 39	6.91		20.39	;	> 3.19	??	77	> 3.1
7	7.30	.21	7.01	7.34	.00	.00	7	20. Bi	ł	.00	13.90	13.80	.0
	4.90	. 41	4.21	6.90	.00	.00		20.15	ł	.00	13.66	13. 14	.0
•	4.50	. 34	6.12	6.50	.00	.00	9	17.87	;	.00	13.77	13.77	.0
10	7.30	. 48	4.82	7.30		.00	10	20.48	:	.00	13.44	13.66	.0
11	7.30	. 20	7.10	7.30	.00	.00	11	20.66	ł	.00	13.54	13.56	.0
12	6.90	. 50	6.40	6.90	.00	.00	12	20.14	ł	.00	13.74	13,74	.0
13	4.20	.50	5.70	4.20	.00	.00	13	17.50	ł	- 00	13.00	13.40	.0
14	6.20	.21	5.71	6.20	.00	.00	14	19.38	;	.00	13,47	13.47	.0
15	7.40	.75	6.65	7.40	.00	.00	15	29.32	;	.00	13.47	13.47	.0
16	6.40	. 65	5.75	á. 40	. 4	5.72	16	19.25	;	.03	13.50	13.52	13.5
17	4.90	.25	4.45	4.90	. 34	4.54	17	19.81	ł	.01	13.16	13.23	13.2
11	8.50	.27	8.23	8,00	. 20	7.80	18	21.11	ł	.43	12.00	13.21	13.3
17	7.90	.25	7.45	7.90	.12	7.50	19	21.15	;	.07	13.50	13.55	13.5
20	8.70	.17	7.93	8.70	.00	.00	20	21.12	ł	.00	13, 19	13, 19	.0
21	8,40	.33	8.07	8, 40	.00	.00	21	19.15	ł	.00	11.08	11.06	
22	7.30	.54	4.74	7.30	.58	4.72	22	20.00	:	.02	13.26	13.28	13.2
23	7.80	.70	7.10	7.80	.00	.00	23	20.30	;	.00	13.20	13.20	.0
24	7.30	.45	4.85	7.30	.00	.00	24	20.08	:	.00	13.23	13.23	
25	No Bata	: 1-11	inst eri	11ed.			25	19.17	:				

The depth to water and depth to product are calculated from the tape readings and are shown in the fourth and seventh columns in Table 1. The datum elevation is the reference elevation for the top of the casing on the well where the tape reference was noted. The last four columns of Table 1 show the calculated val-

10/14/83

ues for product thickness, water elevation, piezometric elevation and product elevation. The product thickness is the difference between the depth to water and the depth to product. The water elevation is the datum elevation less the depth to water. If product is present, the piezometric surface is determined for gasoline plumes by multiplying the product thickness by 0.8 and adding the result to the water elevation. The density of gasoline is approximately 0.8, and this calculation corrects for the difference in density and provides a value that would be the water table surface if no gasoline were present. The product elevation is determined by subtracting the depth to product from the datum elevation.

Piezometric Surface Map

The piezometric map is a representation of what the water table surface would be if there were no gasoline in the wells and is based on the density of the hydrocarbon in the well. The piezometric surface indicates static head in the wells which reflects the pressure gradients that determine the direction in which groundwater will move. The gasoline usually will follow these gradients, and the location of the recovery well is based on the shape of the piezometric surface. The depression well should be located where it will intercept the leading edge of the plume and take advantage of natural gradients to minimize the amount of water that will be pumped.

Product Thickness Map

The product thickness map shows the thickness of the gasoline



Figure 4 Hydrograph for Observation Well

column in each of the monitor wells. The thickness of gasoline in a well does not reflect the thickness of the soil that is saturated with gasoline but does indicate the relative abundance and mobility of the gasoline in the vicinity of the well.

Hydrograph

The hydrographs present the data from one well and show how the fluid levels and gasoline thickness have changed with time. Fig. 4 is a hydrograph for a well and illustrates the changes that have occurred in the well since monitoring began in December. Hydrographs make small changes and the development of trends more apparent than the maps do, while the maps show how the changes occur spatially.

CASE HISTORY

The following case history involving two service stations is illustrated in Fig. 5 through 9. Service Station A was our client. In the course of defining the plume from a leak at Station A, we discovered an equally large amount of gasoline in the ground on the west side of Station B (Fig. 5). The two service stations are separated by a 4-lane highway and are bounded on the east by a 6lane highway. Our task was to recover the gasoline under our client's station and not bring the plume from the other station onto our client's property. We followed the procedures explained in this report using two recovery wells.



Figure 5 Piezometric Surface Elevation in Feet 20 Days After Beginning Operation



Product Thickness in Feet 20 Days after Beginning Operation

The plume under Station B was mitigated by our competitor who chose to use an approach of daily well purging. We were allowed to collect monitor well data from both stations throughout the recovery operation.

Fig. 5 shows the piezometric surface 20 days after the two recovery wells were turned on. There was a cone of depression established for Station A to control the spread of the gasoline. Fig. 6 shows the product thickness for both stations. The plume under Station B was very large because there were as yet no monitor wells to define the true extent of the plume.

Fig. 7 shows the piezometric surface 9 months later. The recovery well located on the southeast side of Station A was turned off at this time because a recovery well finally had been installed at Station B. The effect of the cone of depression from the Station B well and our recovery well would have caused the plume under Station B to migrate to our client's property. Fig. 8 shows the product thickness 9 months after the recovery wells were put into operation. The plume under Station A was greatly reduced in thickness and extent while the plume under Station B was smaller only because wells had been installed to indicate the accurate extent of the problem.

Fig. 9 shows the product thickness map 1 year after startup of the recovery wells. The second recovery well was turned off in July, and the tanks were removed from the station. The local fire marshal would not allow tank removal until the product thick-



Piezometric Surface Elevation in Feet 9 Months after Beginning Operation

ness around the tanks was less than 1 ft. There still were minor amounts of gasoline in the monitor wells in the curb lanes of both streets adjacent to Station A, but the ground under the station no longer had any free hydrocarbons on its surface. The wells in the streets were purged monthly for the next year and the site was then determined to be clean. In this instance, the presence of dissolved hydrocarbons in the groundwater was not an issue.

Fig. 9 also shows that after a year of frequent well purging there was still a significant amount of gasoline under Station B. The recovery well on the property was never operated systematically. Two years after the recovery operation began, a new 2story office building had been built and occupied on our client's property. The Station B property was abandoned with more than 1 ft of gasoline remaining in some monitor wells.

CONCLUSIONS

The systematic manipulation of the piezometric surface to control the migration of free hydrocarbons is a reliable and easy method of mitigating these spills. The use of piezometric surface data to manage the recovery compensates for the unknown parameters of soil permeability with respect to the hydrocarbon, flow velocities or attempts to determine the true volume of the spill. Recovery and liability control are achieved using simple field measurements methods.





Figure 8 Product Thickness in Feet 9 Months after Beginning Operation

This approach has been used successfully in 15 recovery operations. It was superior when applied to a situation where the soil and water table conditions were identical under two service sta-

Figure 9 Product Thickness in Feet 1 Year after Beginning Operation

tions; one station used the plume and liability control strategy described in this paper, while the other service station used a different recovery approach.

Mobile Treatment Technologies

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ABSTRACT

The role that mobile or transportable waste processing systems will play in future Superfund site activities appears to be increasing. These systems, which presently are employed to treat some RCRA wastes, appear to apply to the treatment of CERCLA wastes.

Mobile treatment systems usually consist of modular equipment that can be brought onto a site (e.g., by truck or railcar) and can be used on a number of different sites over the life of the equipment. Size and configuration of the equipment may differ considerably from the conventional equipment used in permanent structures.

The information in this paper will provide policy planners, onscene coordinators and remedial managers with guidance for the implementation of mobile treatment systems. The paper presents a review of applicable treatment technologies currently used as mobile systems. Waste characteristics, environmental impacts, costs and other development and implementation factors are considered in assessing the potential role of these mobile systems.

INTRODUCTION

The use of mobile or transportable technologies for the treatment of hazardous wastes has shown increasing promise for application to the CERCLA program. Some of these systems presently are being employed for the treatment of hazardous wastes regulated under the RCRA program, while other mobile treatment systems currently are being developed as pilot units. The opportunity for technology transfer of these technologies from RCRA to CERCLA, as well as further development from the pilot stage, represents an important challenge to the Superfund program.

The mobile treatment systems considered in this paper usually consist of modular equipment that can be brought onto a site (e.g., by truck or railcar). When the cleanup is complete, they can be transported to a number of different sites over the life of the equipment. Size and configuration of the equipment may vary considerably from the conventional equipment used in permanent structures. In general, the equipment is smaller than conventional equipment in order to allow for mobility. One large piece of equipment, however, may be in several parts on separate trucks, trailers or railcars. The equipment also may consist of several removable components in order to accommodate the needs of several sites. Mobile treatment systems may be skidmounted, prepiped and prewired for fast response to emergency situations or they may require assembly on-site before operations commence and then require disassembly prior to transporting to another site.

Mobile systems show considerable promise for remedial activ-

ities at Superfund sites. These technologies can provide a permanent solution with many advantages over alternatives involving off-site transport and disposal. While the experience base is somewhat limited, interest in mobile systems is growing rapidly. The number of venders offering viable systems has increased dramatically in recent years.

Several cautions should be exercised, however, before more resources are committed to process technologies. The complexity of Superfund wastes, many of which have been fully integrated into the environment for many years, has required the application of labor intensive mobile technologies to deal with the variable field conditions (i.e., the changes in waste composition and the regulated waste effluents). Even inert materials in the contaminated wastes (i.e., silts, clays, debris, rocks and iron) may create significant waste processing and handling problems. Abrupt changes in waste composition make it very difficult to apply process control instrumentation to these wastes. Moreover, since most mobile treatment systems are smaller than stationary systems their application to the smaller hazardous wastes sites may be limited and prevent the mobile concept from being the "total solution" to the cleanup of uncontrolled hazardous wastes sites.

PAST AND PRESENT USE

The concept of using mobile treatment systems to process water and wastes is fairly well-established. The United States Department of Defense has developed and used mobile water treatment units to provide potable water and to treat sewage. Additionally, many conventional wastewater treatment systems have been modularized to the extent that small-scale systems can be practically considered transportable (e.g., equipment on oil rigs, ships and airplanes).

The application of the mobile concept to uncontrolled hazardous waste sites is not new. Under U.S. EPA sponsorship, mobile equipment has been developed for emergency response and has been used to contain, collect and, in some cases, provide preliminary treatment of accidentally released hazardous materials and contaminated groundwater. The types of mobile equipment developed by the U.S. EPA for emergency responses include:

- Carbon adsorption/sand filter system
- Rotary kiln incineration system
- In situ containment/treatment system
- Soil washer system
- Activated carbon regeneration system
- Flocculation-sedimentation system
- Reverse osmosis treatment system
- Independent physical/chemical wastewater treatment system

Experience with the use of mobile systems at Superfund sites is limited, but the concept has been or is being incorporated for both remedial response and waste removal. Some past and/or ongoing activities involving mobile systems at uncontrolled hazardous waste sites are described in Table 1.

Table 1 Mobile System Use at Uncontrolled Hazardous Waste Sites

Sile	Status (as of) 1/86	Vaste Type	Treatment Technology
Bridgeport, NJ	Completed	Aqueous/Oily Lagoon Vaste Contaminated with PCBs	Physical/Chemical
	Design	PCB Contaminated Sludge/Soils	Incineration
Times Beach, HD	Design	Soile Contaminated with Volatile Organics	Incineration
Acme Reclaiming, IL	Dezign	Soil Contaminated with Low Levels of Organics	Incineration
Love Canal, MT	Construction	Leachate from Chemical Dump	Plasma Arc (Thermal)
Bog Creek Farm, NJ	Design	Sludges/Soils Contaminated with High Levels of Organics	Incineration
	Design	Soils Contaminated with Low Levels of Organics	Soil Vashing/ Extraction
	Design	Surface Vaters	Chemical Treatment and Air Stripping
NcKin, MH	Design	Soils Contaminated vith Volatiles	Nechanical Aeration
Triangle Chemical, TX	Design	Soil Contaminated with Volatile Organics	Mechanical Aeretion
Old Inger, LA	Design	Organicalliy Contam- inated Sludges & Soils	Landferning
Picillo Farm	Completed	Phenol Contaminated Soil	In situ bio- degradation
Lee's Farm, VI	Design	Soils Conteining Lead	Soil Vashing/ Extraction
Vide Beach	Design	PCB Contaminated Soils	Chemical Treatment/ Extraction
Seymour Recycling, IN	Completed	Surface Runoff	Physical/Chemical
Resolve, MA	Completed	PCB Contaminated Sludge	Stabilization/ Solidification
Bruin Lagoon, PA	Construction	Acid Asphaltic Sludges	Stabilization/ Solidification
Davie Landfill, FL	Design	Sludges	Stabilization/ Bolidification
NCAdoo Assoc., PA	Design	Soil Contaminated with Organics	Stabilization/ Solidification
Tysons Dump, PA	Design	Soil Contaminated with Organics	Stabilization/ Solidification
Bio-Ecology	Design	Haavy Hetal Sludges & Soils	Stabilization/ Solidification

Note: Some designs have been delayed pending reauthorization.

In spite of the increased use of mobile treatment systems for both emergency responses and remedial actions at hazardous waste sites, there are many factors that have contributed to the very limited application of mobile systems at Superfund sites. These factors include:

- Generally higher costs and longer periods for development and operation
- Developmental nature of some technologies
- Local institutional issues of concern

• Limitations of capacity, materials handling or process characteristics that prevent the mobile concept from being a total solution

FUTURE USE

Land disposal of hazardous waste is becoming less acceptable as a means of managing uncontrolled hazardous waste sites. Policymakers are realizing that land disposal does not offer a final solution to the hazardous waste problem—rather than providing a method of treatment, land disposal often provides only temporary containment. As a result, many wastes will be restricted from land disposal within the next 5 years. Developing alternatives to land disposal is, therefore, imperative.

Cost, availability and reliability are three of the key factors used to determine which systems are preferable to others. The development climate with respect to these three factors appears to be changing in favor of mobile systems. The following points summarize some of the favorable aspects of these systems:

- As more systems are developed, cost, reliability and availability will continually improve.
- Although several innovative mobile technologies have large capital equipment costs, those equipment costs may be applied to many sites and be shared by those projects.
- Mobile on-site treatment may be preferable to off-site stationary facilities in cases where permitting is an important issue. The exemption of the on-site system from some permitting requirements may make the mobile alternative more attractive.
- The ability to manage the waste handling, treatment and disposal activities on-site has many inherent advantages for remedial action planners and managers.
- A number of vendors have expressed interest in developing a mobile system to meet the needs of Superfund. In addition, the state of Illinois has requested bids for mobile incineration systems.
- Many fixed technologies are currently available and are used by a number of large industries for RCRA wastes. Modifications of these units (i.e., smaller sizes and modular construction) to accommodate mobility probably could be accomplished in a relatively short time (less than 6 months).

There are a number of impediments to development and commercial use of mobile treatment systems. Some of these impediments are:

- Shortage of reliable and comparable technical performance information and standardized cost data
- Uncertainties in scale-up of designs from bench- or pilot-scale
- Uncertainty in the performance and treatment standards for many pollutants
- Substantial delays and cost increases resulting from complicated procedures for environmental permitting
- Difficulty in obtaining liability insurance to cover operational risks during development and testing of various technologies
- PRP concerns about liability in the event of innovative technology failure
- Hesitation by states to use innovative technologies given the perceived uncertain reliability of such technologies
- Tendency of concerned communities surrounding Superfund sites to prefer remedial alternatives that remove all hazardous substances to a management facility that is far from the site; innovative on-site technologies may, therefore, appear less attractive from the adjacent community's point of view.

In spite of these impediments, options are being considered and, in some cases, used to remove them and/or create incentives to promote development of innovative mobile technologies. For example, CERCLA amendments now pending may solve the PRP concerns about liability by allowing the U.S. EPA to indemnify those participating in cleanups. In addition, state support for mobile systems is increasing. Illinois has requested bids for mobile incineration systems. New York currently owns a pyrolysis (plasma arc) system and will be testing it soon at one of its hazardous waste sites.

PLANNING CONSIDERATIONS

Mobile treatment systems can be designed and operated to handle almost any waste type processed by permanent units. Limited experience using these systems necessitates, however, a very close assessment of their applicability, design and operation on a case-by-case basis.

There are many planning considerations that must be incorporated into an assessment of the viability of mobile systems for a particular site. The direction provided in U.S. EPA guidance documents on planning remedial investigations and feasibility studies is very useful in this assessment. Some of the more critical planning considerations are:

- Waste characteristics
- Site constraints
- Potential environmental impacts
- Costs
- Technology support requirements

Each factor will be addressed in the subsequent sections.

Waste Characteristics

It is important to identify and assess both favorable and restrictive characteristics of wastes with respect to each treatment system. Examples of characteristics to consider in selecting a treatment system are:

- Waste variability and requirements for treatment performance -some technologies can handle a wide range of wastes with consistent treatment performance while others are more susceptible to variable waste conditions.
- Non-Toxic waste components—operational problems such as fouling and plugging of equipment can result from innocuous components such as iron, suspended solids and naturally occurring organic materials.
- Need for pretreatment—some wastes may require a more elaborate treatment process while others may be treated by a less capital intensive treatment process such as fixation/solidification.

Each mobile technology system must be reviewed to identify the waste types that can be processed with that unit. Restrictive waste characteristics, i.e., wastes with characteristics that may interfere with efficient operation, and requirements for both pretreatment and post-treatment should also be identified.

Site Constraints

When locating equipment on the site (or immediately off the site), one should consider many factors such as:

- Impact on the local community
- Security of the equipment
- Existence of adequate electric utilities
- Roads for large trailer accessibility
- Water supply
- Sewer lines
- Slope stability of the land
- Soil conditions
- Flood plains
- Local zoning ordinances

Mobile treatment systems should rely as much as possible on existing utilities in order to speed implementation and to prevent unnecessary capital expenditures on auxiliary equipment. Site preparation required to operate a mobile system may include:

- Access roads
- Concrete pads for equipment
- Accidental spill control and staging
- Connections to public utilities

Potential environmental impacts must also be weighed in the equipment siting decision.

Potential Environmental Impacts

Environmental impacts are an important consideration with regard to mobile treatment systems:

- Air pollution can be a major concern for incineration systems and air stripping systems.
- Constituents must be identified and their transport away from the facility must be anticipated under worst case situations (e.g., stagnant air and thermal inversions).
- Road construction and intensive activity on-site may create additional pollution problems such as airborne particulate dust, surface runoff and erosion. These emissions of fugitive dust are of particular concern if disturbed soils are contaminated.
- Noise generated during waste treatment or during equipment transport may disturb nearby residents.

Every effort should be made to minimize these impacts by selecting the proper location for the mobile units and by following good engineering practices. The health and safety of the workers as well as nearby residents must be considered, and sufficient precautions should be incorporated into the remedial program design.

Residuals generated by the selected treatment process must be handled in an environmentally safe manner in order to minimize future potential environmental impacts. The concentration and quantity of residuals must be assessed early in the selection process to incorporate proper treatment and/or disposal into the overall process. Extensive requirements and/or restrictions with respect to residuals for one treatment process may make the use of other treatment technologies more favorable.

Although the potential for negative environmental impacts does exist, mobile treatment systems offer many beneficial environmental impacts for the remediation of Superfund sites including:

- On-site treatment systems eliminate the need to transport contaminated materials to off-site facilities. As a result, potential risk during transport is eliminated.
- Mobile treatment systems could reduce the implementation time for remedial action and prevent further contamination.
- Mobile systems can treat source materials efficiently and minimize the overall impact due to extensive removal and activities.

Costs

The cost of implementing mobile treatment technologies is also important in determining the preferred alternative. There are five major cost concerns that may affect the selection of one technology over another:

- With all alternatives, capital, operating and maintenance costs must be carefully reviewed to assess the economic impacts to the remedial program.
- Several innovative mobile technologies have large capital equipment costs. If a specific technology is applied to numerous sites, however, the cost of the equipment can be shared by

these projects. The end result would be savings in the Superfund program. Mobile treatment may, therefore, provide the advantage of using higher cost technologies on Superfund sites.

- Many mobile units have not been used extensively at Superfund sites. Therefore, cost data are not yet available.
- Waste-specific conditions can greatly affect the costs of a remedial program, and efforts to provide detailed cost estimates for these technologies usually must be made on a case-by-case basis.
- Labor-intensive efforts may be required for mobile systems due to the high variability of the waste; however, these costs can be offset by reduced handling and disposal costs of the residuals.

Technology Support Requirements

The use of specific mobile treatment systems should include an assessment of:

- Utilities required (e.g., electricity, water, wastewater, fuel and cooling) for system operation
- Availability of utilities at the site and the services required for the treatment system (e.g., laboratory and maintenance)
- Extent of training required for the operating labor force; in

general, the labor force for a mobile treatment system used at a Superfund site will require more training because the monitoring requirements for the process operation will be more intensive than for permanent treatment systems or for nonprocess alternatives.

The reasons for the additional training are:

• Solid

Noderate - 90%

- Field operation of mobile treatment systems, particularly in the initial stages, may be labor intensive
- Automatic control systems are employed less often
- The variability of the waste requires a significant monitoring ٠ effort

CONCLUSIONS

A summary of the planning considerations for several mobile technologies (Table 2) is included to provide a qualitative review for comparison with other technologies. Descriptions of the waste types, the removal/destruction capability, the residual generated, the residual management and the relative costs are detailed for each mobile technology. The management of residual side streams and effluents may require additional processing steps

TECHNA OCY	Poblie Unit	Primar; Types	y Waste Treated	Removal/ Destruction	Reduction of	Air Entssion or Residues	Further s Treatment/ Hanagement	Relat Estimated	lve costs
TIERMAL TREATMENT	Status	<u>C1855</u>	Form	Capability	Waste Volume	Generated	Required	Capital	
Incineration Rotary Kiln Liquid Injection	Commercial Commercial	0 0	5,L L	Very High Very High	iligh High	A,L,S A,L,S	inorganics in ash/landfll inorganics in ash/landfll	1 High I High	High High
Fluidized Bed/		•		Very LH ob	Hinh		increasing in achilandfil) Mich	High
Infråred	Pilot	0	5,L 5,L	Very High	High	A,L,S	thorganics in ash/landfil	1 High	High
Pyrolysis									
Plasma Arc	Pilot	0	ι	Very High	litgh	A,L	inorganics in ash/landfil	1 High	High
Advanced Elec. Reactor	Pilot	0	5,L	Very Iligh	lligh	ĄL,S	inorganics in ash/lanifil	1 High	ili gh
"Wet Oxidation"									
Oridation	Pilot	0	1 04	Very High	iliob		increasing in treated str	exe Hinh	High
Wet Air Oxidation	Commercial	ŏ	L.	High	Horierate	L	Inorganics/organics in treated stream	High	High
INTOULLIZATION									
Fixetion/Solidification									
Cement-based	Commercial	1	S	High	None	A	Landfill	Low	low
Flyash or Lime-based Asphalt-based	Commercial Pilot	1	s dry S	lligh High	None None	Å	Landfill Landfill	Low Hedium	Low Hed fum
REMOVAL TECHNOLOGIES									
Chemica)									
Uxidation-Reduction	Connercial	1.0	S.L.OM	Moderate	Hoderate	A.S	Devatering/Landfill	Low	Hed fum
Neutralization	Conmercial	1,0	S.L.GW	lligh	Hoderate	A, S	Dewatering/Landfill	Low	Hedlum
Precipitation	Connercial	1	L,GW	Huderate	iligh	S	Devatering/Landfill	Low	Hedium
Dechlorination	Connerciai	0	L,S	High	High	L,S	Land())	Hed ium	High
Physical .		_							
Distillation	Connercial	0	L,GW	iligh	lligh	L	Recycle/destruction	High	High
Steam Stripping	Connercial	<u>.</u> .	S.L.CW	liigh	iligh	L L	Recycle/destruction	High	High
Phase Separation	Conmercial	0,1	5, L	Moderate	Poderate	L,S	Landfill/destruction	Hoderate	Low
Air Stripping	Connercial	0	GW, 5	ifigh	High	A, L	Treatment of air emission	s Low	LOW
Clarification	Comercial	ÿ		wery High Medealte	ilign Madaasta	L.	Carbon Regeneration	High	High
Exercised for	Commercial		UW,L	HOHEFALE	Noterale	L, 2	Langrill Landfill (death such inc.	LOW	line
Soil Hatbion	Dilot	8. i	<u>ل</u> ،،	Maduante	in ga	- <u>-</u>	Landiiii/destruction	Low	Noderate
Filtration	Compectal	, ,,	2110	lich	nign	L, 3	Develop (Logifil)	Hoterate	Moderate
100 Exchange	Connercial		CN.C.3	Yucy illoh	lich	, ,,,	Becycle /destruction	LOW	Hoderate
Hombrane Separation	Pilot	ó, 1	GW,L	Very High	iligh	ì	Recycle/destruction	ili gh	High
Biological Treatment									
Aerobic	Comercial	0	GW, L	High	Hoderate	L,S	Dewatering/landfill/	1	Law
Anaerobic	Commercial	0	GW,L ,S	liigh	Hoderate	L .S	Dewatering landfill	Low	Low
	<u> </u>						Fait	sions or Resid	
Mobile Unit Status Connerctal + Full Scale/0	Decational		Waste C	lass <u>Has</u>	te Form	Re	noval Efficiency Gene	rated Byproduct	<u> </u>
Pilot = Demonstration Sca	le/Operationa	1	I • Ino	rganic L	Concentrated LI	quid Ill	rynngas->ччх A.⊧ gh-95X L.=	All' Liquid, concent	trated

GW . Groundwater

(low concentration)

Table 2 Summary Data on Missile Technologies

and increase costs. Thus, planning considerations should thoroughly evaluate the treatment and/or disposal of these residuals.

In summary, the transfer of treatment technologies from RCRA wastes to CERCLA wastes into a mobile configuration shows great promise for the cleanup of uncontrolled hazardous wastes sites where the remedial action can be accomplished within a reasonable timeframe. The application of mobile treatment technologies will allow more capital intensive technologies to be used for the cleanup of hazardous waste sites, sharing the costs between several projects. The application of mobile technology will result in a decrease in the total cost for the cleanup of each Superfund site.

The technology transfer, however, is complicated by the uncharacteristic nature of CERCLA wastes, and the application of these mobile technologies must be reviewed on a case-by-case basis. The use of a mobile treatment technology at a particular Superfund site may require extensive laboratory and/or pilot scale treatability studies to assess the specific application to Superfund wastes.

Response to an Underground Fire At an Abandoned Hazardous Waste Landfill

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ABSTRACT

An underground landfill fire on the south side of Chicago, Illinois, was reported to the U.S. EPA in August of 1985. The scene of the fire was previously an industrial waste disposal facility owned by the U.S. Scrap Corporation. The facility reportedly operated from the late 1960s through 1975 during which time industrial waste and debris were disposed on-site in pits; industrial wastes were also burned in an incinerator.

In response to actual and potential threats to human health posed by the fire and other side conditions, the U.S. EPA conducted a removal action under authority of CERCLA. This paper details both the efforts at extinguishing the uncontrolled underground fire and at mitigating potential threats posed by the alleged presence of chemical, shock-sensitive, radioactive and biological wastes in an elevated railroad roadbed bordering the site. Emphasis has been placed on the U.S. EPA's utilization of advanced technology in monitoring and mitigating site conditions.

INTRODUCTION

The U.S. Scrap Corporation (U.S. Scrap) was an industrial waste disposal facility located on the south side of Chicago, Illinois (Fig. 1). The abandoned site was brought to the attention of the U.S. EPA on Aug. 16, 1985, when an official employee with the Chicago Metropolitan Sanitary District (MSD) reported dense smoke emanating from several areas of the hazardous waste landfill. In addition to the potential threats posed by the off-site migration of toxic gases, U.S. EPA and Technical Assistance Team personnel identified a second serious potential hazard posed by the site; namely, the alleged presence of shock-sensitive and toxic waste within the landfill. The remainder of this paper summarizes the site's physical properties and operating history and the U.S. EPA's response to the two major hazards posed by site conditions.

SITE DESCRIPTION AND OPERATING HISTORY

The U.S. Scrap site measured approximately 270 by 1,600 ft (Fig. 2). The site was bounded on the west by a railroad embankment, on the south and east by a sewage treatment facility operated by the MSD and on the north by an industrial area. Residential areas were located 1,500, 3,000 and 4,000 ft east, north and south of the site, respectively. Notable physical features on the site included an access road leading to the southern end of the property, a loading area and industrial incinerator near the center of the site, and sludge pits and eight concrete silos along the site's eastern edge.



Figure 1 Site Location Map, U.S. Scrap, Chicago, Illinois



Site Map U.S. Scrap Landfill, Chicago, Illinois

While the exact dates of operation are not known, it has been reported that this drum reclamation facility began accepting waste in the late 1960s and was closed by 1975. Wastes from reclaimable drums were emptied into pits excavated on-site while other drums, whose condition was such that recovery was not feasible, were buried within the same pits. In addition to these recovery and disposal practices, the company also allegedly operated under the guise of an incineration facility.

During interviews with past U.S. Scrap employees, it was alleged that past disposal practices included the burial of drums containing pesticides, shock-sensitive wastes and hospital wastes. The hospital wastes were allegedly in the form of lab packs containing radiated biological research wastes, blood specimens and body parts. Reportedly, these drums were implanted into the railroad embankment along the western border of the site; the common procedure used was to excavate a small cavity into the embankment, place three or four drums into the opening and subsequently cover the drums with the excavated fill.

A hospital that was contacted for the purpose of gathering additional information confirmed that it had sent several types of waste to the U.S. Scrap site for disposal. It was estimated that ether and radioactive wastes would be very abundant within the lab pack materials. The origin and actual volume of other wastes that reportedly were buried within the embankment were unknown.

Prior to the CERCLA-funded action described in this paper,



Figure 3 Location of Regional Air Monitoring Stations

there had been limited attempts at securing a comprehensive cleanup of the site. There was, however, a partial removal of onsite waste under an agreement between the responsible party and federal, state and local agencies. This action resulted in the removal of 100 drums of liquid hazardous waste stored within the silos and an estimated 10,000 gal of sludge within drainage swales.

U.S. EPA INVESTIGATIVE AND MITIGATIVE ACTIONS

Proper response to any emergency situation involving hazardous materials involves the following three key tasks: (1) identification of the materials involved, their distribution and their inherent threats as determined by their specific chemical and physical characteristics; (2) assessment of the threats posed to the general public, the environment and the responding personnel; and (3) mitigation of these threats after prioritizing each and evaluating the feasibility and effectiveness of alternative actions. It was within this framework that the U.S. EPA conducted a comprehensive investigation and timely removal action at the U.S. Scrap Landfill. As described in the following discussion, priority first was given to the underground fire as it posed the most immediate potential threat to the health and well being of residents and workers in the vicinity.

Response to the Underground Fire

The primary objectives of investigative efforts upon mobiliza-

tion to the site on Aug. 11, 1985, were to characterize the air emissions originating from the site and to document the location and nature of the underground fire. Within hours after the initial response, the gases emanating from fissures or "vents" created by subsidence were partially characterized, and the primary burn areas within the fill were identified through field observations. Initial air monitoring efforts revealed the presence of compounds such as hydrogen cyanide, hydrogen chloride, hydrogen sulfide, benzene and acetone. Some of the compounds are known to be acutely toxic at low levels, while others are classified as carcinogenic.

Subsequent to the discovery of these compounds, the U.S. EPA: (1) directed the cleanup contractor to begin applying clay caps on all venting areas; (2) expanded the air monitoring and sampling program to document air quality; and (3) initiated additional efforts to define the extent of the underground fire. The fire had, at this point, progressed to the stage where flames at the vents were clearly visible in brightest daylight.

Air Monitoring

The air monitoring performed during this phase of the response further characterized the off-gases in order to protect personnel conducting on-site investigations and mitigative operations; air quality in adjacent residential areas also was determined in order to ensure the protection of public health.

Several air monitoring techniques were employed in support of on-site activities at the U.S. Scrap site. Real-time monitoring instrumentation utilized included combustible gas indicators, organic vapor analyzers (OVA), photoionization detectors (PID), permissible toxic gas indicators and colorimetric detection tubes. The OVAs and PIDs detected organic gases at concentrations approaching 200 ppm in areas near the vents. Of the four types of permissible toxic gas indicators used (i.e., phosgene, hydrogen cyanide, hydrogen sulfide and hydrogen chloride), all detected concentrations above their respective alarm levels with the exception of phosgene. Colorimetric tube results correlated well in the identification of these compounds.

The detection of toxic gases in the vent gas and the knowledge that large amounts of solvents and other volatile materials were burned at the site suggested that off-site releases of contaminants may have been occurring. Therefore, an eight-station offsite monitoring program was concurrently operated in conjunction with the on-site program. The eight stations established in neighborhoods surrounding the site (Fig. 3) were attended every 8 hr and monitored for airborne contaminants. This monitoring, maintained throughout the duration of the fire, did not detect off-site releases of those compounds identified through on-site air sampling.

The precise delineation of the aerial extent of the underground fire was obtained through the use of two innovative technologies: infra-red photometry and thermocouple temperature probes. The photometry was conducted at night; an infra-red camera was taken aloft by a light, fixed-wing air craft. The air craft would perform low altitude (minimum of 1,000 ft) over flights of the U.S. Scrap site while the infra-red images were recorded on video equipment allowing for later viewing and interpretation. For purposes of establishing proper scale and accurate mapping of burn areas, reflectors (in this case two by two foot aluminum foil) were placed in a 50- by 50-ft grid pattern over the entire site (Fig. 4). The initial over flights revealed the presence of two major burn areas (Fig. 5). This information proved invaluable as the burn areas were shown to extend beyond the venting areas that were initially capped to reduce contaminant emissions.

Burn Area Delineation

In conjunction with the infra-red photometry, the U.S. EPA

conducted subsurface temperature monitoring through the use of thermocouples implanted approximately 3 to 4 ft below the ground surface (Fig. 5). In addition to monitoring the intensity and horizontal migration of the fire, the temperature probe data were correlated with the infra-red images. This correlation allowed rough approximations of the subsurface temperature without requiring the relocation of probes.

The data collected by the U.S. EPA through its investigative efforts documented several substantial threats to human health. The landfill fire was releasing volatile organic compounds and various toxic gases resulting in a direct contact (i.e., inhalation) threat. Left unattended, the fire could have intensified and emitted higher volumes and concentrations of those compounds, thus increasing the potential for air contaminant migration into adjacent residential areas. This threat, in addition to the threat of explosion of subsurface wastes, demanded that the underground fire be totally extinguished. Toward this end, several methods for extinguishing the fires at the U.S. Scrap site were identified and evaluated.

Remedial Action

Considerable discussion between all involved responding personnel generated six options to extinguish the fires. These options were:

- Continued remote monitoring with additional capping of each burn area
- Application of large volumes of water over burn areas with passive infiltration
- Subsurface injection of cryogenic inert gases into burn areas
- Artificial raising of the perched water table under burning masses
- Construction of a surface pond over the burning masses
- Exhumation of burning material and extinguishment above ground

After intensive evaluation, taking into account public health, feasibility, potential for positive results and cost, the capping option was selected. The cap required approximately $1,600 \text{ yd}^3$ of clay and was put in place within 2 days.



Figure 4 Site Control Grid, U.S. Scrap Landfill

Infra-red overflights and thermal probes monitoring indicated the northern burn area to be burning in a southerly direction, out from under the capped area. Therefore, a second application of clay was required. The cap proved to be highly effective and eliminated a majority of the on-site air emissions. The cap was periodically watered to inhibit the cap from cracking. Once the capping technique appeared to be effectively controlling and extinguishing the burn areas, permanent temperature probes were installed to enhance the definition of the thermal anomalies.

To add further definition of subsurface gas composition, a soil gas survey was conducted by the U.S. EPA Environmental Response Team (ERT). The survey identified the presence of a complex array of organic compounds, including benzene, toluene, ethyl benzene, xylene and trichloroethylene. This survey correlated closely with the data from several soil samples that had


Figure 5 Underground Fire Location Map, U.S. Scrap Landfill, Chicago, Illinois

been obtained from the site.

Within 3 weeks, the temperatures decreased gradually to ambient conditions. Once the fire was completely extinguished, the second serious potential hazard posed by the site was addressed.

RESPONSE TO WASTE IN THE RAILROAD EMBANKMENT

Consistent with the aforementioned emergency response framework, the U.S. EPA first determined the types of waste and their distribution within the embankment, second assessed the threats posed by these materials within the physical setting at the U.S. Scrap site and third performed a removal action to eliminate and/ or mitigate the respective health and environmental hazards. The remainder of this section discusses the various actions undertaken within each stage of the response.

The task of characterizing the nature and location of buried waste, prior to actual exhumation, required considerable effort. As mentioned previously, the U.S. EPA obtained information on the types and quantities of waste within the embankment from the reports of waste generators suspected of having sent waste to the site and from interviews with former U.S. Scrap employees. During these interviews, it was alleged that past disposal practices included the burial of drums containing pesticides, shocksensitive wastes and hospital wastes (the latter were in the form of lab packs containing radiated biological research wastes, blood specimens and body parts). Visual scans of the embankment tended to confirm the alleged burial practices, as several drums were protruding from the ground. To further corroborate the allegations, and in an attempt to delineate the sections of the embankment used for burial purposes, a geophysical survey was conducted.

Geophysical Survey

The survey was conducted within a sampling grid along a 1,500ft length of the railroad embankment using both an EM 31 electromagnetic conductivity meter and a SCINTREX MF-2 flux gate magnetometer. During the course of the survey, documentation of surface debris that may have affected instrument readings was maintained. The raw data were entered into a Techtronix data processing system that generated contours of the raw data, first partial derivative with respect to the X-axis and first partial derivative with respect to the Y-axis. The results of each survey were correlated and the anomalies were summarized in graphic form (Fig. 6).

The extent of the anomalies suggested that virtually the entire length of the embankment exhibited a high potential for the occurrence of buried ferromagnetic material. Although the survey could not distinguish buried drums from other ferromagnetic material, it did tend to verify allegations made by former U.S. Scrap employees regarding the burial operations along the embankment.

Based upon the rather consistent information obtained from both waste generators and former employees of the operation, the data generated from the geophysical survey and data from limited sampling efforts, the U.S. EPA determined that the waste within the embankment posed a significant threat to public health and the environment. The primary threats cited were fire and explosion and exposure to hazardous substances by nearby populations.

Removal Planning

Subsequent to the determination that the site continued to pose a significant threat, the U.S. EPA began to develop a detailed removal plan. Such a plan was deemed critical as removal of the alleged waste presented complex safety and logistical problems. The resulting plan identified three work phases: (1) preparation of the site; (2) excavation of the drums; and (3) performance of followup studies.



Correlation Between Exposed Drum Occurrence and Geophysical Results

Site preparation activities were extensive and generally consisted of the development of safety and contingency plans, development of materials handling procedure and construction and/or set-up of staging and work zones. The site safety plans for both technical and cleanup personnel were developed based upon conservative projections of the types and quantities of materials that were to be unearthed.



U.S. Scrap Landfill, Chicago, Illinois, Transect Air Sampling Technique

Contingency planning resulted in several pre-excavation actions including:

- Construction of two 10,000 gal pools to aid in extinguishing potential fires during drum handling activities
- Stockpiling of sand to handle potentially exposed air-reactive waste
- Establishment of a communicative system with the Chicago and Western Indiana Railroad Company enabling the coordination of site activities and train movements atop the embankment

Because of the variety and hazards associated with the buried wastes, a materials handling protocol was established. The result-



Figure 10 Correlation Between Anomalies and Survey Techniques

ing decision diagram (Fig. 7) was developed and incorporated into the excavation operating plan.

Proper site preparation also required the construction of several staging and work zones (Fig. 8). Two staging areas were established at the southern end of the site for radioactive and nonradioactive wastes, respectively. Also constructed were detonation bunkers for ignition of shock-sensitive waste and a portable building for lab-pack separation.

Removal Action

The second phase of the removal action entailed the excavation of the drums and the initiation of a comprehensive air monitoring program. Immediately prior to drum removal, personnel from the U.S. EPA's Technical Support Division provided guidance and equipment for radioactive material identification and performed a radiation survey of the entire embankment. The survey revealed no reading above the ambient range. Fire breaks then were excavated every 300 ft along the embankment to minimize possible chain reaction fires and/or explosions. During a 5-day period in mid-October, 1985, 77 drums containing mercaptans, paint residues and resins were exhumed. The expected shock-sensitive, radioactive and acutely toxic materials were not exposed.

Throughout the period of drum exhumation, the U.S. EPA performed both on- and off-site air monitoring. In addition to the standard array of real-time monitoring instruments, portable air sampling pumps and high-volume air samplers were used to obtain data on organic and inorganic airborne contaminant concentrations, respectively. The portable pumps were equipped with activated charcoal collection tubes and were configured according to the transect technique (Fig. 9). A less elaborate configuration of high-volume samplers was maintained. Analysis for both organic and inorganic constituents revealed no constituents significantly above ambient concentrations.

Final Monitoring

The third phase of the response included post-excavation activities such as conducting a second geophysical survey of the embankment and further sampling efforts. The second geophysical survey was performed in early November, 1985. The primary objective was to determine if any ferromagnetic anomalies remained within the embankment. The methodology and equipment used were the same as the first survey with one exception: due to the installation of a 6-ft chain-link fence on the embankment crest, the grid system was shifted 15 ft to the east. Fig. 10 displays the occurrence of the geophysical anomalies, the majority of which were suspected to be caused by surficial metal near the embankment and the recently installed fence. The results, therefore, suggested that the excavation successfully removed all drums within the railroad embankment.

CONCLUSION

The response to the underground fire and buried waste at the U.S. Scrap site incorporated the use of several advanced technologies. The technologies were employed in rapid fashion and enhanced the U.S. EPA's ability to: define and monitor site conditions; identify mitigation alternatives; and minimize both safety risks for on-site personnel and health threats posed to the general public.

Superfund Innovative Technology Evaluation Program

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ABSTRACT

The U.S. EPA has initiated the Superfund Innovative Technology Evaluation (SITE) program to allow it to participate with the private sector in an effort to enhance the use of innovative cleanup technologies in the Superfund program. The SITE program is intended to enhance the development and demonstration of promising innovative technologies and thereby assist in establishing their commercial availability. The program has been described in the SITE Strategy and Program Plan published by the U.S. EPA.

There are four parts of the SITE program including Superfund regulatory and policy analyses, research and development activities, an analysis of the potential demand for specific demonstrated technologies and full-scale field demonstrations of promising technologies at Superfund sites. The SITE program is a joint effort between the Office of Solid Waste and Emergency Response and the Office of Research and Development.

INTRODUCTION

Concern exists over the extensive use of land-based containment technologies to mitigate the problems posed by Superfund sites. This concern has been expressed by the public, the Office of Technology Assessment, U.S. EPA's Science Advisory Board and Congress. The U.S. EPA recognizes this concern and has developed the Superfund Innovative Technology Evaluation program (SITE) to accelerate the development, demonstration, and use of innovative technologies at Superfund sites. The program is jointly sponsored by the U.S. EPA's Office of Solid Waste and Emergency Response and the Office of Research and Development.

The primary purpose of the SITE program is to enhance the development and demonstration of innovative technologies and thereby establish their commercial availability for use at Superfund sites. To accomplish that purpose, the program has four goals:

- To identify and where possible to remove impediments to the development and commercial use of alternative technologies
- To conduct a demonstration program of the most promising innovative technologies to establish reliable performance and cost information for use in site-specific decisions under Superfund
- To develop procedures and policies to encourage the development and selection of appropriate innovative and alternative technologies in lieu of land-based containment technologies at Superfund sites

• To structure a research and development program to nurture emerging technologies

This paper will discuss each of the four parts of the SITE program in further detail and provide a summary of progress in implementing the program. SITE includes a technology transfer, community relations and a communications strategy to assist in ensuring that information developed is made available to appropriate audiences. In addition, the demonstration of promising innovative technologies is the present focus of the SITE program and therefore that effort will be discussed in depth.

BACKGROUND

Under the current Superfund program, the predominant method of remedying a site is to move the wastes to regulated land disposal sites or to contain the wastes on the Superfund site itself. Neither approach is a true remedy; the wastes are neither treated nor destroyed. The contained sites require continued maintenance to ensure that an unacceptable level of contamination does not escape from the system to the environment. In addition, containment systems do not last forever and must be replaced periodically. This places a long-term burden on agencies responsible for ensuring the site's integrity.

The U.S. EPA believes that land-based containment technologies are not appropriate for the Superfund program. Consistent with the intent of the National Contingency Plan, the U.S. EPA prefers to utilize technologies that destroy, immobilize and/or treat contaminants instead of merely containing them. However, the legislative requirement to take costs into account when selecting a remedy and the practical limitations of existing technologies mean that containment systems will not be eliminated altogether.

The U.S. EPA has agreed that there needs to be a comprehensive program to assist industry in developing long-term permanent solutions for Superfund cleanups. It also appears that the legislation reauthorizing Superfund will establish an RD&D program for innovative and alternative technologies. In response to the evidence in favor of such a program, ORD and OSWER have developed and are implementing the SITE program to enhance the commercial availability of innovative technologies for use at Superfund sites.

The terms "alternative technology" and "innovative technology" are widely used central concepts in the SITE program. An alternative technology is any unit operation or train of unit operations that permanently alters the composition of hazardous wastes through chemical, biological or physical means to significantly reduce the toxicity, mobility and/or volume of the hazardous waste or contaminated material being treated. In essence, alternative technologies are any treatment technologies that are alternatives to land disposal. Alternative technologies may be "available," "innovative" or "emerging" (Fig. 1).

Available alternative technologies, such as several forms of incineration, are fully proven and available for routine commercial or private use. Innovative technologies include any fully developed technology for which insufficient cost or performance data exists to allow its routine use. Innovative technologies require full-scale field testing. Emerging alternative technologies are ones for which research has not successfully passed laboratory and pilot scale testing.

The four parts of the SITE program address each type of alternative technology noted above and, as noted earlier, are intended to foster the use of innovative alternative technologies at Superfund sites.

IMPEDIMENTS TO THE USE OF INNOVATIVE TECHNOLOGIES

There are a number of impediments to the acceptance and use of innovative technologies for the treatment of wastes at Superfund sites. Under the SITE program, they are categorized as informational, regulatory and institutional impediments.



Figure 1 Alternative Technologies in Relation to the Technology Development Process

Informational impediments are generally those associated with the fact that if insufficient information exists concerning the cost and performance of a technology, potential users will be reluctant to invest in it. The SITE strategy assumes that there is a shortage of reliable and comparable technical performance information and standardized cost data for innovative technologies and that this deficiency is inhibiting the acceptance and use of such technologies. A major objective of the demonstration program is to develop data to overcome this informational impediment.

Another identified informational impediment is uncertainty surrounding marketing. A market must be defined so developers can decide whether and how much venture capital will be worth risking to pursue the development of innovative technologies. Relevant market related issues include definition and standardization of performance and treatment standards and the long-term outlook for the nation's commitment to Superfund site cleanups. The SITE program will help overcome these barriers through a technology transfer effort, regulatory and policy analyses (including the applications analysis described later in this paper) and general information transfer.

Regulatory impediments to the use of innovative technologies are more generally recognized. The most discussed impediment is the array of permitting requirements, including the delisting of residual wastes that face a potential developer when attempting to bring a technology from the laboratory to full-scale demonstration and into use at a site. Efforts under the SITE program will focus on assisting existing and on-going work groups, task forces and policy groups within the U.S. EPA which have been formed to address regulatory issues. An example of such ongoing groups is the Mobile Treatment Task Force which is investigating impediments and issues concerning the use of mobile-treatment units at Superfund sites. The purpose of such work groups is to solve identified problems over which the U.S. EPA has control. Additional impediments exist which are outside the control of the U.S. EPA.

There are also institutional impediments to commercialization of innovative technologies. Institutional impediments refer to inhibiting factors that are outside the regulatory arena which may affect private parties, communities surrounding Superfund sites and governmental entities. An example of an institutional impediment for a private party is the potential lack of sufficient liability insurance for a developer to risk pursuing his technology. A governmental impediment is the use of a definition of costeffectiveness which encourages the selection of traditional containment systems even though an analysis of long-term costs would result in the opposite conclusion.

Communities near Superfund sites generally prefer solutions which remove the wastes from their area. Therefore an innovative technology treating wastes on-site may not be well received.

The SITE program does not envision a specific study to address identified areas of impediments. Instead, the program will address the problems both through working with established Agency mechanisms to modify policies, guidance and regulations, as necessary, and through generating and disseminating information which may be used by the existing Work Groups, Task Forces, private sector and public.

DEMONSTRATION PROGRAM

During development of the SITE strategy, the Agency's efforts were reviewed and commented upon by a number of experts outside of the U.S. EPA. These individual experts have collectively been referred to as the SITE Strategy Review Group. One of the major points made by that group in its review was that acceptance of a new technology is driven by and dependent upon the level of confidence in the technology by decision-makers and the public. The most important factor in gaining the necessary level of confidence is the availability of pilot and full scale demonstration data indicating that the technology can be considered both operational and reliable. Therefore, to meet the objective of the SITE strategy of moving developed technologies into routine use, the program includes a significant effort directed to full-scale field testing of promising innovative technologies.

The goal of this Demonstration program is to allow the U.S. EPA to evaluate innovative technologies in realistic test conditions so that reliable and comparable cost and performance data is developed and made available. The U.S. EPA's crucial role in the demonstration program is to ensure credibility of the results by defining the testing protocols, test procedures, analytical protocols and methodologies and by performing the quality assurance and quality control function so that the resulting data from the demonstrations can be consistently and accurately interpreted. In addition, the tests to be conducted are to simulate actual conditions as much as possible and are to be performed at full-scale. The end result is to provide performance, cost-effectiveness and reliability data so that potential users have sufficient information to make sound judgments as to the applicability of a given technology and how it compares to other promising technologies.

Consistent with the focus of SITE to accelerate the acceptance and use of innovative technologies, the demonstration program will select technologies that have been fully developed and require only the collection of cost-effectiveness and performance data necessary to determine the credibility of the technique. Alternative technologies which are currently considered available and therefore not innovative (e.g., some forms of incineration) will not be considered for the demonstration program. The focus of the demonstration programs will be technologies that meet one or more of the following criteria:

- Provide a permanent solution, i.e., destroy the contaminant or significantly reduce the toxicity, mobility, volume or combination thereof
- Can be utilized on-site as opposed to requiring costly transport off-site
- Are applicable to a variety of sites and wastes
- Address critical problems that presently have no solution
- Potentially have significantly lower costs than current methods
- Provide significantly better performance than current methods
- Produce manageable emissions, effluents and/or residues from environmental, cost and health viewpoints
- Are easy and safe to operate

The scale of the demonstrations will vary, but generally only commercial scale units will participate. Any demonstration must be at a sufficient scale to ensure that results are credible to users regardless of future scale-up requirements. Likewise, the program will emphasize performing demonstrations at actual Superfund sites to further add to the credibility of results. While all sites will be considered, the priority will be given first to federal-led Superfund remedial and removal sites, then to other state-led and federal facility sites and last to privately owned sites. It also may be possible to conduct demonstrations at ORD test and evaluation facilities if necessary.

The financial relationships between the U.S. EPA and the developer in conducting the demonstrations are somewhat dependent on the final terms of the Superfund reauthorization bill. The bill is expected to provide specific funds to conduct the demonstration program. It is the U.S. EPA's intent that the U.S. EPA and the developer jointly fund the demonstration program. The developer will be responsible for equipment mobilization and demobilization as well as maintenance and operation during the demonstration. The U.S. EPA will fund its costs associated with preparing protocols and procedures, collecting performance and cost data during the demonstration and issuing a report. The U.S. EPA is also considering the potential of funding site preparation activities such as access roads, utility connections, foundations, etc. In addition, the SITE program will be implementing a technology transfer and communications strategy on the program as a whole to disseminate the findings. The U.S. EPA does not intend to reimburse the developer for costs associated with the demonstration unless there is no private source of funds available and the technology is of interest to the U.S. EPA.

Demonstrations will occur under two separate but parallel efforts. The SITE strategy contains a formal process of annual solicitations and selections. In addition, demonstrations will be incorporated into on-going Superfund projects. The two combined efforts will assure that demonstrations are conducted (and subsequent cost and performance data developed) as quickly as possible and that a balanced and fair program for all interested developers is initiated.

SITE DEMONSTRATION PROGRAM

The solicitation/selection process developed for the SITE program is depicted in Fig. 2. While the process is obviously complicated, it is designed to ensure that available technologies are identified and screened, that those with greatest potential are selected and that all developers have equal access to the program. The process will be administered by a steering committee comprised of individuals from ORD's Office of Environmental Engineering and Technology (OEET) and OSWER's Office of Emergency and Remedial Response (OERR).

The process depicted in Fig. 2 includes development of an annual program plan for demonstrations which is comprised of a solicitation of technologies, selection of technologies and a determination of the priority of selected demonstrations. This annual plan will be published and submitted for public comment. During implementation of the annual plan, site specific demonstrations will be planned, conducted and reported upon. While the plan will be established annually, any individual demonstration may last longer than 1 year. Throughout the development of the annual plan and implementation of the individual demonstrations, the U.S. EPA will implement a communications strategy to keep interested parties informed of the program and individual site community relations plans to allow the communities in the vicinity of the demonstrations to comment upon and participate, as appropriate.



Figure 2 Demonstration Program Structure

The process for development of the annual plan involves four primary steps: (1) solicitation of technologies, (2) selection of technologies, (3) selection of demonstrations and (4) public review and comment. The U.S. EPA intends to solicit candidates through advertisements in the *Commerce Business Daily* and through less formal means such as the publication of this paper. To be eligible to participate in the demonstration program, however, a developer must respond to the Request for Proposal advertised in the *Commerce Business Daily*. The proposals then will be formally evaluated based upon: (1) applicability to Superfund (i.e., the eight criteria described above), (2) readiness of the technology and the developer to conduct a demonstration and (3) capabilities of the developer.

As the list of eligible technologies is selected, a process to determine the available sites and, therefore, the demonstrations to be conducted also will be completed. Since it is preferable to conduct demonstrations at actual Superfund sites, the U.S. EPA must actively screen the locations and match them with the promising technologies. Consideration will be given to the wastes and media of concern to the Superfund program to ensure that selected demonstrations are directed to recognized problems. Site selection will consider a variety of factors including potential public acceptance, urgency of the cleanup, PRP involvement. U.S. EPA Regions and/or state agency involvement, status of cleanup efforts at the site and its practicality for use as demonstration site. Selection of the final list of proposed demonstrations will consider the effectiveness of the technology, costs associated with the technology and the risks posed by the technology as compared to conventional technologies. A draft of the annual plan will be published to allow all interested parties to review and comment upon it. After public review and comment, the annual plan will be modified as necessary and then published in final form, and individual site demonstrations will be implemented.

Implementing the site-specific demonstrations after the annual plan is developed will involve several steps normally involved in establishing such a program. Negotiations with the applicant will occur to determine the financial arrangements and the division of responsibilities between the U.S. EPA and the developer. Sitespecific demonstration test plans will be prepared to establish all relevant test conditions such as equipment operating parameters, sampling and analytical protocols, reporting responsibilities and procedures and community and public relations procedures. A community relations program will be implemented during the life of the demonstration including release of the final report.

Once the actual on-site activities are completed, it will be the U.S. EPA's responsibility to prepare a report on the results of the demonstration.

Final demonstration reports will include information such as performance and design parameters, waste characteristics, destruction and removal efficiencies, process residues and wastes, O&M requirements, operational safety considerations, mass flow/energy balances, mobilization and demobilization procedures, instrumentation and control processes and QA/QC requirements. In addition, costs associated with capital, operations, maintenance, unscheduled maintenance, disposal of residues, QA/QC and administration will be reported. If possible, time requirements for design, permitting, manufacture and mobilization will be determined and included in the report. The SITE technology transfer strategy will be developed and implemented to disseminate the test results.

RI/FS DEMONSTRATION PROGRAM

As noted above, there will be an on-going program parallel to the SITE demonstration program just described, which allows the U.S. EPA to respond to opportunities and accelerate the evaluation of technologies. To select the appropriate remedy for a Superfund site, the U.S. EPA performs a Remedial Investigation and Feasibility Study (RI/FS). The RI/FS is conducted to determine the nature and extent of contamination at a site and, therefore, the specific problems which must be addressed. The RI/FS also evaluates the appropriateness of available technologies to remedy the site. Under the NCP, the Agency may conduct pilot tests and treatability studies as part of an RI/FS. Given the U.S. EPA's desire to utilize alternative and innovative technologies, there likely will be occasions where an RI/FS will include the testing of a technology to determine its potential applicability at a specific site.

To ensure consistency and comparability of data on innovative technologies, the U.S. EPA intends to conduct technology evaluations scheduled for tests as part of RI/FSs in a fashion similar to the SITE demonstration program. These evaluations will provide information on the technologies with a broader applicability than likely would occur under a site specific RI/FS demonstration.

In addition, the U.S. EPA may evaluate technologies during the design phase of a remedial project or during a removal action at a site, if appropriate. A test under the design phase of a project or a removal action may occur to ensure the performance of a technology and allow adjustments to its final design to make it applicable to the specific site. Where appropriate, a SITE demonstration type test will be conducted at this stage of the Superfund project as is contemplated for the RI/FS.

APPLICATION ANALYSIS AND POLICY REQUIREMENTS

Successful demonstration of a technology will not guarantee by itself that a technology will in fact be adopted for full-scale use at Superfund sites. In addition to the analysis of impediments and the demonstration programs described earlier, the SITE program includes an analysis of the investment potential and longterm demand for a technology.

The need for an analysis of investment potential and demand stems from the fact that successful technologies for use in the Superfund program will have to be available at a reasonable cost. The determination of what constitutes a reasonable cost is in part dependent upon the demand for the technology as well as the way in which costs are calculated. If a given technology is used at many sites, it is anticipated that its overall cost will be less than if it is used at few sites. Since the U.S. EPA manages the Superfund program, its actions largely determine the ultimate demand (i.e., the number of available sites) for a technology.

SITE, therefore, has included an analysis of the potential demand for a given technology in its program to assist developers in planning for commercialization of their technology. The analysis is not intended to replace the normal market analyses performed by the private sector, but rather will provide information to help improve the accuracy of such analyses as well as assist the U.S. EPA in long-term program planning. The effort primarily will be directed to determine how many sites can use a given technology. This may involve additional tests using surrogate wastes at a test and evaluation facility.

DEVELOPMENT PROGRAM

While much of the SITE program necessarily is focused on technologies that are ready for demonstrations to accelerate their acceptance into routine commercial use, it is recognized that there may be technologies in a lesser state of development which deserve attention. Therefore, the SITE program includes a development program to assist the development of technologies from the laboratory and pilot-scale phases to the demonstration phase. This work usually should be performed by the private sector. However, where attractive technologies have not generated sufficient private sector interest, the U.S. EPA may choose to assist their development.

The development program is similar to the demonstration program. The U.S. EPA will monitor non-federal research and development activities to identify promising technologies. There will be routine solicitations to allow developers to propose a program of U.S. EPA assistance to develop their technologies. The U.S. EPA intends to focus on emerging alternative technologies that deal with recycling, separation, detoxification, destruction and stabilization of hazardous constituents. The selection of technologies for U.S. EPA support will be based on the same criteria as the selection process under the demonstration program plus consideration of the capability of the developer to conduct the work and the costs to be borne by the U.S. EPA.

The program also may involve extensive use of U.S. EPA inhouse capabilities. The Agency has several test and evaluation facilities which may be appropriate to further research and develop specific technologies. If the demand for such facilities grows, the U.S. EPA may improve or modify its facilities or some private sector facilities may be developed to further enhance research of alternative technologies. In general, however, this program is intended to be incorporated into the U.S. EPA's longterm Research and Development programs and become a permanent part of the Agency's hazardous waste programs.

CONCLUSIONS

The U.S. EPA has initiated a major new program to further the acceptance and use of alternative and innovative treatment technologies at Superfund sites. The program is titled the Superfund Innovative Technology Evaluation (SITE) program and will be jointly sponsored by the Office of Research and Development

and the Office of Solid Waste and Emergency Response. The program is in response to the identified need to utilize treatment technologies that actually treat or detoxify or immobilize or destroy hazardous wastes rather than the containment technologies frequently used in the past.

The SITE program is comprehensive in that it consists of four major parts: (1) a program to identify and address impediments to the use of innovative technologies at Superfund sites, (2) a program to demonstrate promising technologies to develop critical cost and performance data for those technologies, (3) an analysis of the potential demand for specific demonstrated technologies and (4) a development program to focus U.S. EPA research and development efforts to foster the development of emerging alternative technologies. The program is designed to be responsive to the needs of the Superfund program, involves extensive public input and includes technology transfer aspects to assist in disseminating as much information as possible to the audiences who need it.

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Applying Alternative Technologies at Superfund Sites

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ABSTRACT

In the past, the U.S. EPA has used land disposal often to manage Superfund hazardous wastes. Efforts are now under way to use alternative treatment technologies to remediate Superfund sites. This paper discusses some of these technologies and describes the U.S. EPA's efforts to encourage the wider application of alternatives to land-based containment.

INTRODUCTION

Currently, CERCLA and the resulting NCP stipulate that remedial actions selected for Superfund must meet two key criteria: (1) remedies must be proven technologies, and (2) remedies must be cost-effective. Therefore, land disposal has been applied at many Superfund hazardous waste sites in the past because it has been considered "proven" and "cost-effective." Unfortunately, these requirements often have inhibited the development and application of new technologies that offer the promise of more permanent solutions to the problem of managing Superfund hazardous wastes.

However, revisions passed in 1984 to RCRA have placed certain restrictions on the use of land disposal. In addition, versions of CERCLA now under consideration specify alternatives to land disposal as the preferred remedial options at Superfund sites. These changes to the U.S. EPA's mandate will significantly increase the use of alternative technologies at such sites.

The U.S. EPA already has begun to use alternatives to land disposal. Thermal destruction has been used for approximately 13% of all past removal actions and is planned for approximately 10% of all future remedial actions. Chemical and physical treatment has been planned for approximately 9% of remedial actions. Although not usually considered an alternative to land disposal, groundwater treatment now is being planned for almost 45% of all remedial actions.

The U.S. EPA has established the Superfund Innovative Technology Evaluation (SITE) program to develop and demonstrate innovative and emerging technologies. Until results from the SITE program are available, however, many existing technologies will be applied to Superfund sites. The following examples illustrate ways that existing technologies can be applied in future remedial actions.

IN SITU ENHANCED VOLATILIZATION OF VOLATILE ORGANIC COMPOUNDS

At the Verona Well Field site in Michigan, soils above an aquifer are contaminated with volatile organic compounds (VOCs). A soil vapor extraction system uses a number of vacuum wells to induce a flow of air through the soil; the volatile contaminants are expected to migrate from the soil into a piping system under vacuum.

Although this volatilization technique is considered to be a new process for treating VOC-contaminated soil, it is similar in principle to some well-established technologies. Air stripping, for example, uses a flow of air through a porous medium to strip VOCs from a stream of water. Another similar technology is landfill gas extraction, in which vacuum wells are used to remove gases from the unsaturated soil zone.

The Problem

The Verona Well Field supplies potable water to most of the City of Battle Creek, Michigan. In 1981, the well field was found to be contaminated. Seven VOCs were identified as the primary contaminants in the well field: 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, cis-1, 2-dichloroethylene, 1,1-dichloroethylene, trichloroethylene and perchloroethylene. The plume of contamination was nearly 1 mile long and 0.5 mile wide. Five existing wells were incorporated into a "blocking well system" designed to arrest the advancement of the contaminant plume.

During the remedial investigation, two facilities operated by a local solvent wholesaling company were identified as major sources of contamination. VOC concentrations as high as 1,000 ppm were found in both groundwater and soil. It has been estimated that the soils on the property contain a total of approximately 1,700 lb of VOCs and that the groundwater in the immediate vicinity of the property contains a total of 3,900 lb of VOCs.

Using a groundwater extraction system alone would prevent the continued migration of the plume. However, using only this system would take a long time to solve the problem because of the slow rate of leaching of contaminants from the soil to the groundwater. Eliminating contaminated soils as a source of groundwater contamination was required to expedite cleanup actions and - restore the well field.

Why This Technology Was Selected

Several alternatives involving the use of "demonstrated technologies" to treat contaminated soils were considered to augment the pumping and treatment of contaminated groundwater.

One alternative was to install a clay cap over the contaminated soils to reduce infiltration by at least 90%, thus isolating the contaminated mass in the unsaturated zone soils. Another alternative was to excavate contaminated soils and dispose of them in an on-site or off-site double-lined landfill, in compliance with 1984 RCRA amendments. It was estimated that 9,300 yd³ of soil would have to be excavated and disposed under the landfill option.

The clay cap and landfill alternatives were rejected because they merely isolated the contaminated soils and provided no real treatment. In addition, construction of an on-site land disposal facility would be difficult because of the limited area of the property. The installation of the clay cap would be difficult because of the narrow range of clay moisture content required to construct an effective cap.

Another remedial alternative evaluated—and considered to be innovative—was in situ soil washing. This alternative would allow clean water to percolate through the contaminated soil. VOCs would be washed into the groundwater, which then would be collected and treated by an extraction well system. This alternative was rejected because it was projected that it would take 8 years to reduce the contamination to acceptable levels.

Thus, the U.S. EPA selected the enhanced volatilization of VOCs using a soil vapor extraction system to augment groundwater treatment. Nearly complete removal of the contaminant mass from the unsaturated zone is expected to occur within 1 year. Through the use of this process, with accompanying treatment of groundwater, VOC contamination in groundwater is expected to be reduced to 100 μ g/l in only 3 years, and VOCs actually will be removed from contaminated soils.

The Technology

This technology reduces the level of contamination in the unsaturated zone above aquifers by inducing, under vacuum, a flow of air through the soil. Contaminants normally are removed from the resulting air stream through the use of an activated-carbon air treatment system.

Wells are installed through the unsaturated zone into the saturated zone; screens are placed in the wells just above and slightly below the water table; and a vacuum is placed on the well, air is extracted and the contaminated air is treated before being released to the atmosphere. As more air is extracted from the soil, the pressure surrounding the well is lowered, with two effects:

- More contaminants volatilize from the soil moisture phase to the soil vapor phase
- Clean air flows from the atmosphere at the surface, through the contaminated soil (where it collects vaporized VOCs), and to the well, carrying the volatile contaminants with it

With a clean source of air and a system of wells with overlapping influences, the contaminants can be extracted from the unsaturated zone.

Applying the Technology at the Verona Well Field Site

The actual design of this system for the Verona Well Field will be developed by the vendor. However, a general system was evaluated in the feasibility study.

A network of approximately eight air extraction wells will be installed at Verona Well Field for the withdrawal of air and volatilized contaminants. The wells will extend approximately 2 ft below the water table. Screens will be placed above the water table and a short distance below the bottom of the unsaturated zone. A conceptual diagram of this system is shown in Fig. 1.

This array of air extraction wells will be connected by an airtight transfer line to a vacuum pump. Because the VOCs are collected through a vacuum system, contaminants can be controlled at a single emission point, and the potential for fugitive losses of air contaminants is reduced. The vacuum pump will be used to draw 100 to 150 ft³/min of air from each well. The combined flow of approximately 1,000 to 2,000 ft³/min of contaminated air from the wells will be directed through a vapor phase carbon adsorption treatment system before being discharged to the atmosphere so that the resulting emissions meet applicable air quality discharge limits. When the carbon has been regenerated in a furnace, the VOCs will have been destroyed.



Figure 1 Enhanced Volatilization with Groundwater Pumping and Treatment will be used at the Verona Well Field Site in Michigan.

Expectations

This in situ enhanced volatilization process has been used successfully in some hazardous waste applications but never at a Superfund site. Enhanced volatilization requires conventional installation materials and equipment, periodic maintenance to ensure effective operation, periodic monitoring of discharge air to guard against vapor breakthrough and periodic monitoring of soil to confirm the expected decrease in contaminant concentrations. The system is anticipated to be installed at the Verona Well Field site in the spring of 1987.

The U.S. EPA anticipates that the system will remove over 90% of the estimated 1,700 lb of VOCs in the unsaturated soil zone within the first year of operation. The cost to construct and operate this system for 1 year is estimated to be \$410,000. Because this technology is expected to destroy the volatile organic contaminants, annual operating and maintenance costs are not expected.

SOLIDIFICATION/STABILIZATION OF ORGANIC COMPOUNDS

Solidification/stabilization of soils contaminated with lead, arsenic and PCBs is the alternative selected for the Pepper's Steel and Alloys site in Florida. Use of this technology at the Pepper's Steel site is innovative since it is to be used with soils contaminated with PCBs and other organic compounds. Solidification physically reduces the movement of water through the soil mass, reducing advective transport from the soil and decreasing the exposed surface area and the diffusion potential. Stabilization chemically binds constituents within the soil, reducing dissolution and diffusion rates.

The Problem

The site covers 30 acres of an unsewered industrial area approximately 10 miles northwest of Miami. Groundwater is about 5 to 6 ft below the ground surface and is part of the Biscayne Aquifer, a sole-source aquifer that supplies all of Dade County's water. Contaminants identified within the soil, sediments and groundwater in and around the Pepper's Steel site include PCBs, organic compounds and several heavy metals. PCBs, lead and arsenic are present in soils in high enough concentrations to warrant remedial action.

Studies estimate that there are approximately 48,000 yd³ of PCB-contaminated soils with concentrations greater than 1 ppm; 2%, or approximately 1,000 yd³, exceed 50 ppm. In addition, oily concentrations of PCBs were detected in test pits dug on-site.

It is estimated that $21,500 \text{ yd}^3$ of soil are contaminated with lead at concentrations exceeding 1,000 ppm. The volume of arsenic-contaminated soil exceeding 5 ppm is estimated to be about 9,000 yd³.

Why This Technology Was Selected

Several methods of disposing of contaminated soils were evaluated, including off-site disposal, solvent extraction of PCBs, onsite incineration and off-site incineration. Off-site disposal was eliminated from consideration because it was more costly than other alternatives and it added transportation risks. Solvent extraction was not selected because the technology was considered to be experimental and costs were very uncertain. Incineration was considered and rejected because of the problems associated with the volatilization and release during incineration of heavy metals contained in the soils. In addition, there still would be a need to dispose of a significant amount of residuals from materials collected by the air pollution control system and from metal-contaminated soils remaining after incineration.

Solidification/stabilization was the selected alternative because it is expected to control the movement of constituents in soils by solidifying soil particles and by stabilizing (chemically binding) the constituents within the soil, thus reducing their mobility.

The Technology

Cement-based and pozzolanic materials have been used to immobilize a wide variety of hazardous and radioactive wastes. When tailored to a specific waste, these materials can produce a matrix that resists leaching and degradation in a geochemical environment. However, these materials must be carefully matched to the specific wastes to be immobilized and to the physical characteristics of the site. In the past, solidification was not thought to be applicable to organic contaminants.

A suitable mixture of solidification reagents and solidification aids has been developed to lock the metals and PCB-contaminated soils from the Pepper's Steel site into a solidified mass. This mixture has passed the engineering performance criteria and leaching criteria established by the U.S. EPA for the site. The U.S. EPA will continue to monitor groundwater in the vicinity of the site to assure the effectiveness of this technology.

Applying the Technology at the Pepper's Steel Site

At the Pepper's Steel site, this process will be used on soils with levels of contamination exceeding 1 ppm PCBs, 1,000 ppm lead or 5 ppm arsenic. Contaminated soils will be solidified/stabilized and disposed of on-site. In addition, concentrations of PCB-contaminated oils that are uncovered during excavation will be removed and disposed of off-site. In effect, soils with heavy metals will be chemically stabilized, while soils contaminated with PCBs will be solidified. Research conducted for this remedial action established that a fixing agent consisting of 40% Portland cement and 60% fly ash could be mixed with contaminated soils to form a concrete-like material.

No liner will be used for an on-site disposal system because solidified materials are expected to adequately prevent contaminant migration. Future institutional controls on land use and future monitoring of the effectiveness of the remedy will be implemented at the site.

Expectations

Tests conducted on solidified materials prepared with soils from the site have indicated that this remedial action has a high probability of success. Three leaching tests were conducted, including the EP toxicity test. Soil samples were spiked with oils containing 2,000 ppm PCBs to assure that the samples repre-



Figure 2 Contaminated soils from the Pepper's Steel Site in Florida were solidified and tested for strength and leaching.

sented a conservative oil loading. Under laboratory conditions, the solidified material exceeded all engineering strength criteria set for the project and was reported to have met leaching performance criteria for lead, arsenic and PCBs. Testing of a concrete cylinder made with soils from the site is shown in Fig. 2.

The U.S. EPA has estimated capital costs for applying this technology at the Pepper's Steel site to be \$5.2 million, with an annual cost of \$260,000 during remediation. Project operation and maintenance costs, primarily for post-remedial groundwater monitoring, are estimated at \$42,000 annually. Construction of this remedial action is expected to begin next year.

ENCOURAGING THE USE OF AVAILABLE ALTERNATIVE TECHNOLOGIES

While many alternative technologies currently are available for use at Superfund sites, there often are impediments to their use. These impediments involve such issues as liability, economic and marketplace uncertainties, regulatory and permitting requirements, delisting, federal procurement and public acceptance.

Steps are being taken to remove these impediments. The U.S. EPA is considering procedures "equivalent" to RCRA for delisting treatment residuals at Superfund sites. "Up-front" conditional delisting at off-site test and evaluation facilities is being considered. A two-step formal advertising process is being established to allow more flexibility in the procurement of technologies for Superfund cleanups. In addition, the U.S. EPA is trying to streamline the permitting process and prioritize the permitting of treatment technologies.

Another example of actions the U.S. EPA is taking to help promote the use of alternative technology is the Superfund Innovative Technology Evaluation (SITE) program, which has been established to help overcome the problem created by the lack of cost and performance data available for certain technologies. Innovative technologies will be demonstrated at full scale and on real wastes at Superfund sites; the first SITE demonstrations are scheduled to begin by mid-1987.

Through such demonstrations, it is hoped that the commercial availability of alternatives to land-based containment systems will be expedited. The results from these tests will provide the cost and performance data necessary to evaluate the techniques for use at other Superfund sites. Once this cost and performance information is available, it must be delivered to those who can apply it. The U.S. EPA is developing a technology transfer program to accomplish this.

CONCLUSION

Congress, the U.S. EPA and the public all are seeking longterm, reliable solutions to the problem of managing Superfund hazardous waste sites. Land disposal of hazardous waste no longer will be the preferred remedial alternative for Superfund sites, and programs such as SITE have been initiated to encourage the development of information on technologies for future use.

However, there are existing technologies that can be used at Superfund sites now. The two technologies described in this paper and others currently being applied at Superfund sites are evidence that alternatives to landfilling hazardous wastes exist. The U.S. EPA is identifying and removing impediments that discourage the wider application of alternative technologies. Future policies and guidance will promote efforts to find more permanent solutions to the disposal of hazardous wastes.

Field Verification of the HELP Model for Multilayer Hazardous Waste Landfill Covers

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ABSTRACT

Data obtained from two field-scale experimental landfill covers are used to verify the ability of the Hydrologic Evaluation of Landfill Performance (HELP) model to predict the performance of a multilayer soil cover system. The HELP model uses algorithms based on the physics of soil water movement to predict percolation into the waste layer and resulting leachate production.

The data used for HELP model testing were obtained from experimental covers, each consisting of a 2-ft soil barrier layer overlain by a 2-ft sand drainage layer and topped with a 2-ft vegetated soil layer. The covers, which were 89 ft \times 20 ft with a 3% slope in the longitudinal direction, were large enough to require field-scale compaction equipment. Extensive density and moisture testing was conducted during construction of the soil barrier layers. Measures employed in construction of the barrier layer were later incorporated into the U.S. EPA's Construction Quality Assurance for Hazardous Waste Disposal Facilities Draft.

A thorough description of the procedure used for estimating soil parameters is given. Major HELP model input parameters were derived from soil analysis (particle size and specific gravity), soil moisture characteristic curves and soil classification (USDA and USGS). These initial parameters were employed in the HELP model to predict values of runoff, drainage and percolation volumes for the covers, which are compared with actual field data.

The HELP model is shown to be capable of estimating drainage from and percolation through, a multilayer soil cover for the specific geometric conditions of this site. Advantages and limitations of the HELP model are also presented.

INTRODUCTION

This paper presents an assessment of the HELP (Hydrologic Evaluation of Landfill Performance) model based on intensely instrumented and monitored field-scale multilayer landfill covers. Components of this analysis include: (1) results of the multilayered cover experiment especially as affected by construction differences; (2) procedures and results of the HELP model analysis, including a thorough discussion of input parameters; (3) advantages and limitations of the HELP model, and (4) conclusions.

The HELP model was developed under an Interagency Agreement between the U.S. EPA Municipal Environmental Research Laboratory, Cincinnati, Ohio and the U.S. Army Waterways Experiment Station at Vicksburg, Mississippi.¹ The program is a quasi-two-dimensional hydrologic model of water movement into, through and out of a landfill. The HELP model was intended for use as a design and review tool so that alternate landfill designs could be rapidly evaluated with regard to expected amounts of surface runoff, subsurface drainage and leachate. The program models the hydrologic processes occurring in a landfill system including surface runoff, infiltration, percolation, evapotranspiration, soil moisture storage, lateral drainage and leachate production.¹ The experimental site used in this analysis concentrates on the cover portion of a landfill. The cover system, if properly planned, designed and constructed, is the primary line of defense against the production of leachate and the associated need for leachate containment and/or treatment.

Three multilayered, field-scale covers were constructed,² and have been comprehensively monitored for the past 22 months. The multilayered cover experiment consists of three 6 m by 27 m cells. Each cell has three layers: a lower clay barrier, a middle drainage layer of sand, and an upper topsoil layer. All layers are 0.6 m thick.

A nearly automatic data acquisition system has been installed. Data ports are scanned every second and summed for 5 min to 1 hr intervals, depending upon predetermined criteria which define significant changes. Instrumentation provides data on in situ soil moisture at 48 locations and soil temperature at 28 locations throughout the multilayered cover profile. Data which allow for construction of complete hydrographs of surface runoff, subsurface lateral drainage and leachate are automatically recorded. In this study drainage is defined as that flow which is collected from the sand layer above the barrier layer and leachate is the moisture that percolates through the barrier layer and is collected in a lower drain layer. Standard climatological data, including precipitation, evaporation and wind velocity, are also collected. Thus, all hydrologic and climatologic information necessary for assessing the predictive capability of the HELP model is collected by sensors within this field-scale, multilayered cover system.

MULTILAYERED LANDFILL COVER PERFORMANCE

Data Summary

The data discussed herein are for the 12-month period from October 1984 through September 1985. The HELP model comparisons are based on the second and third constructed covers. The first cover was developed as a construction demonstration cell and has only minimal instrumentation. A summary of hydrologic data from covers 2 and 3 is presented in Table 1.

Construction Effects

A cursory review of the data contained in Table 1 shows that there is a significant difference in the overall performance between covers. Although the construction of the clay barriers in covers 2 and 3 was quite similar, the method and sequence of topsoil placement varied between covers. The resulting performance differences have significant regulatory ramifications. Many

Table 1 Hydrologic Summary of Multilayer Cover Performance

	Oct. 84 -	June 85	July 85 -	Sept. 85	Total	
Qty. (in.)	Cover 2	Cover 3	Cover 2	Cover 3	Cover 2	Cover 3
1) Precip.	30.22	30.22	14.15'	15.16	44.37°	45.38 ²
2) Surf. Runoff	1.66	0.89	1.16	0.09	2.82	0.98
3) Drainage	16.64	9,54	5.44	5.33	22.08	14.87
4) Leachate	1.80	1.31	0.70	0.54	2.50	1.85
5) (2) + (3) + (4)	20.10	11.74	7.30	5.96	27.40	17.70
6) (1) – (5) ¹	10.12	18.48	6.85	9.20	16.97	27.68

1 (1) - (5) = evapotranspiration + net change in soil moisture

2 Different amounts of artificial rainfall were applied using the modified Kentucky rainfall simulator.

regulatory and research efforts have almost exclusively focused attention on the clay barrier. Recent studies have been directed toward laboratory and field permeability, with respect to both water and leachate, as well as field infiltrometer studies.^{3,4,5,6} The draft "Construction Quality Assurance (CQA) for Hazardous Waste Land Disposal Facilities''⁷ directed activities toward insuring a field tested landfill cover, again with respect to the clay barrier. Certainly, a well-documented clay liner is essential, but the hydrologic performance of the complete multilayered landfill cover system needs to be considered. This research documents that construction activities with respect to the uppermost topsoil layer can either benefit or impair the effective performance of the clay barrier. The total performance of the multilayer system is affected by each layer.

In order to understand the results presented in Table 1, the reader must be aware of the differences between covers 2 and 3 in regard to construction of the topsoil layer. In constructing the experimental multilayered covers, emphasis was placed upon the clay barrier layer. The construction sequence and method was carefully specified and well monitored to ensure consistent results. The sand drainage layers did not differ between covers. But the topsoil layer was only specified with respect to design depth and slope; and the investigators, with the concurrence of the U.S. EPA project officer, decided to illustrate the effects of alternative topsoil construction techniques.

A skid-steer front end loader was used to simultaneously place the sand drainage layer and the overlying topsoil layer. Starting from the downsloped end of each cell, the sand was dumped to the maximum distance of the loader's extension. Then topsoil was placed on top of the sand and used as a driving surface for additional sand. Cover 2 was constructed by dumping almost the entire 0.6 m layer of topsoil at the downslope end of the cover and then progressing toward the upslope end, while constantly compacting previously placed topsoil. The uppermost topsoil layer was roto-tilled to about the 10- to 15-cm depth to prepare a seedbed for establishing vegetation. It is expected that such a construction sequence created a hardpan approximately 15 cm thick at about 15 cm below the surface. The remaining 30 cm below the hardpan received less compaction due to its distance below the tires of the loader. Thus, cover 2 was difficult to roto-till, and it had difficulty in establishing a hardy grass cover, likely due to poor root penetration and development.

On cover 3, rather than progressively placing a 0.6 m topsoil layer along the entire cover length, a 15 cm "driving surface" was constructed over the entire area of the cover. This layer became very dense from being repeatedly driven upon. The remaining 45 cm topsoil layer was placed by driving the entire length of the cell, dumping the material, and backing out. Since the uppermost 45 cm of topsoil in cover 3 was never driven over, it was not compacted at all. Consequently, no topsoil seedbed preparation was required nor was root penetration or development inhibited. A vegetative cover was easily established on cover 3.

Another phenomenon observed on the surface of cover 2 was the occurrence of desiccation cracks prior to establishment of vegetation. If these cracks extend into, or through, the compacted portion of the topsoil layer, they provide a ready pathway for water to infiltrate into the relatively uncompacted lower portion of the topsoil layer. These combined factors have resulted in a relatively high hydraulic conductivity. The upper 45 cm of cover 3, which are relatively loose, are also expected to have a high hydraulic conductivity. But it is likely that the denser 15 cm layer, at the bottom, impedes moisture movement into the sand, resulting in moisture buildup into the upper topsoil layer. Moisture is thus retained for a greater length of time in the topsoil of cover 3 and subjected to evapotranspiration. Also, the looser soil and the presence of soil moisture in the lower portion of the topsoil layer has encouraged the development of a thick root system that deeply penetrates the layer and extracts more soil moisture.

Figs. 1 and 2 demonstrate that differences in drainage between covers 2 and 3 can be attributed to differences in evapotranspiration. The graph of drainage for December (Fig. 1) when evapotranspiration is relatively low, shows drainage patterns which are similar in both shape and magnitude for both covers. However, in June (Fig. 2), cover 3 has significantly lower peaks and lower





Figure 2 Drainage from Covers 2 and 3, June 1985

overall quantity of drainage than cover 2. Figs. 1 and 2 also show that drainage in cover 2 responds 1 to 3 days earlier than that of cover 3.

HELP MODEL ANALYSIS

This section of the paper provides brief background material on the methodology of the HELP model. Input parameters of the HELP model encompass the areas of geometry, soil characteristics and climate. Initial estimates of input parameters are applied to the HELP model, and computer predictions are compared to measured data for covers 2 and 3.

Input Parameters

The HELP model requires three types of input parameters: (1) geometric, (2) soil characteristics and (3) climatic. The geometric parameters are defined by design and construction criteria. Required input geometry encompasses: (1) number of layers, (2) layer type, (3) thickness, (4) slope at the base of all drainage layers and (5) cover area. The "layer type" is a numeric designation that indicates whether a layer is represented by: (1) vertical percolation, (2) lateral drainage, (3) soil barrier, (4) waste or (5) soil barrier with an impermeable flexible membrane liner.¹ The covers constructed for this research all have three layers which are from the surface downward: (1) a vertical percolation layer, (2) a lateral drainage layer and (3) a barrier soil layer. All layers are approximately 61 cm thick. The cover is sloped 3%. Therefore, the base of the drain layer in the cover is also sloped 3%. Cover area is nominally 167.2 m². Actual cover area ranges from 167 m² to 177.5 m².

The soil parameters required by the HELP model include the hydraulic conductivity (K) and field capacity (FC) of all layers, the porosity of the vertical percolation layer and the lateral drainage layer, and the wilting point (WP) and evaporation coefficient (EVAPC) of the vertical percolation layer.

Field capacity and wilting point are terms used, mostly in agriculture, to define levels of soil water available to plants. Field capacity is defined as the water content remaining after free drainage from an initially saturated soil has practically ceased.⁸ Wilting point is defined as the water content of a soil at which plants wilt and fail to recover their turgidity when placed in a dark humid atmosphere.⁸ Since these values are not easily determined, they have been somewhat standardized by assuming that field capacity is the water content corresponding to 33.5k Pa soil suction and that wilting point corresponds to 1520k Pa soil suction.^{9,10} A pressure-plate apparatus was used according to the procedure presented in Ref. 11, to determine the needed field capacities and wilting points.

Porosity values were determined as a first step in the pressureplate procedure. The saturated water content, on a weight per weight basis, was determined gravimetrically. Knowing the saturated water content and the specific gravity of the soil, it was then possible to calculate the volume per volume saturated water content, which is approximately equal to the porosity. The bulk density could then be obtained, based on the saturated sample, and used to convert later (unsaturated) gravimetric water contents to volumetric values. A limitation of the pressure-plate method, for characterizing the barrier layer soil is that the remolded sample is typically not compacted to maximum density. Therefore considerable consolidation may take place as the pressure is increased to various levels. Thus the estimated value of field capacity must be somewhat in error. Fortunately, a sensitivity analysis showed that the HELP model is not sensitive to the field capacity of the barrier layer.

The results of the pressure-plate analysis are more important for the topsoil (vertical percolation layer) because the HELP model uses all parameters for that layer. Since the topsoil layer is normally not highly compacted in the field, the pressure-plate procedure is more representative of field conditions. For purposes of initial parameter estimation, the previously mentioned differences between the topsoil layer of covers 2 and 3 were disregarded. Once a soil layer is placed in the field, samples can be taken to determine in situ porosity, field capacity and wilting point. But a designer attempting to use the HELP model to compare alternate designs prior to construction would not be afforded this luxury. The estimated topsoil parameters, from the pressureplate experiments, were very similar to typical values given under the USDA Soil Classification system for loam, while the particle size distribution resulted in a USDA classification of silty loam. The values of K and EVAPC corresponding to loam¹ were used as estimated parameters to describe the vertical percolation layer.

Parameters required in the lateral drainage layer (sand in this case) are porosity, FC and K. Again, the porosity based upon a saturated sample should relate well to the field case, because sand will not consolidate much under pressure. In fact, the porosity was estimated to be 0.340 while the typical value listed for coarse sand (USDA textural class) is $0.351.^{1}$ However, the estimated value of field capacity using the pressure-plate appeared very low. It was 0 .041 vol/vol as compared with a published value of 0.174 vol/vol for coarse sand. The very low number indicates that the sand has almost no capillary suction. Particle size analysis of the sand used resulted in a USDA soil textural classification of "sand." Schroeder *et al.*¹ gives 6.62 in/hr as an estimated value of K for that USDA class. A sensitivity analysis showed that for this geometry the HELP model was not very sensitive to the K value of the drain layer₃ so the value of 4.7×10^{-7} cm/sec was used.

The one parameter not yet discussed is the K of the barrier soil layer. As with many of the previous parameters, it is impossible to know what that value is prior to construction of the layer. The clay soil which was used in the experimental covers was tested and classified as a CH soil according to the Unified Soil Classification System. Such soils are expected to be "practically impermeable" when compacted, which generally means having a K less than 1×10^{-7} cm/sec (1.417 $\times 10^{-4}$ in/hr).¹² Therefore, 1×10^{-7} cm/sec was used as the input parameter for the HELP model. Table 2 gives a summary of the design soil data used as input to the HELP model.

Table 2 Initial HELP Model Inputs

Parameter	Vertical Perc. Layer	Drain Layer	Barrier Layer
Porosity	0.523	0.34	
Field Capacity	0.376	0.174	0.352
Wilting Point	0.217		
K (in/hr)	0.21	6.62	0.000142
Evaporation Coeff. (cm/sec)	4.5		
Vegetation	Good Grass		
Evaporation Zone	25 cm		
Curve Number	81 (default)		

The primary climatologic data required by the HELP model are daily precipitation, mean monthly temperatures and mean monthly insolation. The daily temperature and insolation are estimated from mean monthly values by fitting the monthly values to a simple harmonic curve with an annual period.¹ The precipitation used is the actual daily amount recorded by the tipping bucket raingauge.

HELP Model Performance with Initial Parameter Selection

The capabilities of the HELP model were first tested using the initial parameters listed in Table 2 and on-site daily precipitation data for October 1984 to June 1985. Comparisons were based on the overall model performance, i.e., totals for the entire tested time frame and not on a daily output basis. The overall model predictions are compared to measured cover performance, for covers 2 and 3. As can be seen in Table 3, the HELP model, using these initial parameter estimates, underpredicted surface runoff, drainage and leachate production. This underprediction of flows for both covers indicates that the HELP model, using estimated parameters and Lexington, Kentucky climatic data, overpredicted evapotranspiration. The total predicted HELP outflow quantities were underestimated by 56%, and 24%, for cover 2 and 3, respectively.

 Table 3

 Initial HELP Model Test (Oct. 1984 - June 1985)

Results	Runoff (in.)	Drainage (in.)	% Error	Lenchate (in.)	% Error	Total (in.)	% Error
Cov. 2	1.66	16.64		1.80		20.10	
HELP Model	0.58	7.53	- 55	0.83	- 54	8.94	- 56
Cov. 3	0.89	9.54		1.31		11.74	
HELP Model	0.58	7.53	- 21	0.83	- 36	8.94	- 24

HELP calculated leachate quantities were also underpredicted by 54% and 36% for covers 2 and 3, respectively. However, these HELP model results were based on "best estimates" of what constructed cover parameters might be expected to be and not on in situ measurements, i.e., from the perspective of a knowledgeable design engineer. In this regard, model predictions within 50% are considered quite good.

Additional HELP Model Tests

Additional testing of the HELP model included testing of default procedures, calibration testing, and a sensitivity analysis. Soil samples were tested and classified according to USDA soil textural class and the HELP model was applied using strictly default soil parameters. The default procedure of specifying a compacted layer was tested based on the construction procedures for covers 2 and 3. A compacted vegetative layer was specified for covers 2 and 3 were then treated separately in model calibrations. Tests indicated that realistic variations in input parameters could result in model predictions closely matching actual data. A sensitivity analysis was then performed on the calibrated input parameters. For a complete discussion of these test procedures and results see the final U.S. EPA project report.¹³

ADVANTAGES AND LIMITATIONS OF THE HELP MODEL

Advantages

The HELP model has several advantages which make it a potentially valuable design tool. The model uses published methods to model the effect of all the major hydrologic processes of moisture movement and balance in a landfill. The model ties all of the processes together into a computer program which makes it feasible to model long time periods. Especially important is the inclusion of a daily evapotranspiration algorithm in facilitating long-term simulations.

The HELP model is designed to allow for various layer con-

figurations and drainage lengths that are typical in a landfill design. This flexibility allows for very quick comparisons of drainage and leachate predictions for alternative landfill designs. The computer program includes default climatologic data for 102 cities and it has detailed default data for soil characteristics. The default data also facilitate relative comparisons based upon different climates or different soil types.

Limitations

Some of the algorithms used by the HELP computer program to model the various components of water movement have specific limitations. One potential limitation of the HELP model is that water is not allowed to move laterally in a designated vertical percolation layer. That limitation is not a serious problem for this particular study. However, in many typical landfills a drainage layer is not used between the vegetated layer and the barrier layer. If there is a significant difference in hydraulic conductivity between the two layers, the upper layer would certainly act as a lateral drainage layer (assuming the barrier layer is sloped). This particular limitation can be partially overcome by separating the vegetated layer into two segments for use in the model. The upper segment would be a lateral drainage layer with the same hydraulic conductivity.

Another limitation indicated by results of this experiment is that flow in the topsoil layer may not be strictly idealized porous media flow. However, that is a limitation of any model for saturated/unsaturated soil water movement which is based upon the mathematical equations for porous media flow. Potential users of the HELP model should be aware that the predictions have much greater chance of validity if all soil materials (including the topsoil layer) are placed as uniformly as possible.

Finally, the inclusion of default soil data is a very attractive feature of the HELP model. However, the parameters are presented in the HELP model manual,¹ for the various USDA textural classes, as if they are established values. An inexperienced model user may incorrectly assume that, if the soil can be classified according to textural class, its characteristics are "known." Yet practically any natural soil type can be worked or compacted such that the soil characteristics will not be consistent with those listed in the manual.

CONCLUSIONS

The HELP model proved to be capable of estimating drainage and leachate production based on initial parameter estimates of tested cover materials. The HELP model performs well, for this application and could be used to document the expected performance of alternative landfill cover configurations. It is recommended that a range of feasible input parameters be tested to produce estimates of leachate production on which future recycling, treatment and/or hauling cost can be projected.

ACKNOWLEDGMENT

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Application of Fluorescence and FT-IR Techniques to Screening and Classifying Hazardous Waste Samples

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ABSTRACT

Fluorescence spectroscopy has been applied successfully to screening, classifying and semiquantitating hazardous waste samples from U.S. Department of Defense sites. Fluorescence methodologies provided a cost-effective and time-saving alternative for detecting, classifying and semiquantitating real world samples containing petroleum oils or classes of hazardous chemicals which are relatively strong fluorescers such as polychlorinated biphenyls (PCBs) or aromatics, etc. In addition to standard emission methods, excitation and synchronous scanning techniques were employed as well as both room and low temperature measurements.

Fourier transform infrared spectroscopy also was used for confirmation. It is a complementary technique which is sensitive to nonaromatic and nonfluorescing species.

Reference spectral libraries were developed in-house for reference petroleum oils for both fluorescence and infrared spectra. Spectral search routines based on appropriate feature sets and similarity measures are being developed and tested. Pattern recognition parameters used for spectral searches and comparisons include such factors as spectral areas, peak positions and ratios and angular distances between spectra regarded as vectors in ndimensional space.

INTRODUCTION

This paper is a continuation of a series of studies by one of the authors on pattern recognition and forensic identification for petroleum oils and hazardous chemicals by various spectroscopic methods including fluorescence, low temperature luminescence and infrared spectroscopy which resulted in several publications¹⁻⁸ and ASTM standard methods.^{9, 10} In addition, many tests and publications have dealt with general considerations of fluorescence spectroscopy to identify and classify oils¹¹⁻²⁰ and chemicals²¹⁻²⁶ and similarly with infrared spectroscopy of petroleum products²⁷⁻³⁴ and hazardous chemicals.³⁵⁻³⁸

The present study extends a similar pattern recognition approach to topics of interest to the Corps of Engineers for U.S. Department of Defense (U.S. DOD) environmental projects under Defense Environmental Restoration Account (DERA). For these environmental projects, it is desirable to classify crude and refined petroleum oils and related fuels as to type and probable origin, to classify or identify hazardous chemicals and sometimes to quantitate concentrations of oils and chemicals present in soil, water and unlabelled drums.

The present study has successfully applied fluorescence (emission, excitation and synchronous), low temperature luminescence and, to a limited extent for comparison, Fourier transform infrared (FT-IR) spectroscopy to screening, classifying and semiquantitating hazardous waste samples from DERA sites in Alaska and Kansas. Fluorescence methodologies provide a relatively inexpensive and quick approach to detect, screen, classify and semiquantitate environmental samples involving petroleum-derived constituents or hazardous chemicals having fluorescing aromatic or heterocyclic ring systems, e.g., phenols or polychlorinated biphenyls (PCBs).

In addition to standard emission methods,^{6, 9, 24} less common techniques such as synchronous and excitation spectra were utilized at both room and low (77 %) temperatures. As has been demonstrated by several authors including Lloyd,^{17, 18} Vo-Dinh²⁰ and Eastwood,^{1, 2} synchronous spectra permit more spectral structure and hence enhanced pattern recognition capabilities. Low temperature luminescence spectral. ^{3, 24} generally have greater emission intensity, more spectral structure and phosphorescence as well as fluorescence, thus expanding the number of chemicals which can be studied by molecular emission techniques.

With appropriate reference standards and emission techniques, petroleum oils and fluorescent hazardous chemicals also can be quantitated over a range from 100 ppm to a few ppb even in difficult matrices such as river sediments, therefore accomplishing by a simple technique what would be difficult to do by standard GC-MS methodology.

For comparison with real world samples for classification and pattern recognition purposes, there is an evident need for appropriate spectral reference libraries of known petroleum oils and hazardous chemicals of known purity. Obviously, these reference spectra should be taken under the same instrumental and experimental conditions and preferably should be measured on the same instrument. This is especially important for mixtures such as oils where the emission spectrum will vary with excitation wavelength and bandpass. Matrix effects, concentration effects, possible solvent shifts and effects of emulsions and possible weathering effects must be taken into account. Fortunately, earlier studies of weathering effects on fluorescence and dispersive infrared^{3-5, 27, 28, 34} spectra of petroleum oils allowed estimation of the extent of these effects.

Spectral search routines for classification based on appropriate feature sets and similarity measures were developed and tested. For fluorescence, these included such pattern recognition techniques as computer library searches and comparisons of factors such as spectral area, peak positions and angular distances between spectra regarded as vectors in n-dimensional hyperspace.

Preliminary studies on FT-IR were used for confirmation and as a complementary technique. Appropriate libraries of reference petroleum oil spectra are being developed in-house and, for FT-IR, libraries of hazardous chemicals are already available. Pattern recognition techniques for infrared spectra of petroleum oils included peak positions and peak ratios and angular distances using 20-dimensional space (based on 20 infrared peaks commonly used for oil identification).

EXPERIMENTAL

Instrumental Conditions—Fluorescence

A SPEX Fluorolog 112A corrected spectrofluorometer was used for all fluorescence data collected. The instrument consisted of a single excitation monochromator and a double emission monochromator. The gratings were ruled at 1200 grooves per mm and were blazed at 250 nm (excitation) and 500 nm (emission). The excitation source consisted of a 150 W ozone generating Xenon lamp. Photomultiplier tubes used for both emission and reference detectors were Hamamatsu type R928P and were operated at 950 v and 500 v, respectively.

The spectrofluorometer was interfaced to a SPEX DM1B spectroscopy laboratory coordinator which was programmable in Basic. This data system provided digitized spectral data, disc storage and ease of spectral manipulation.

Calibration of wavelength accuracy was checked by analyzing anthracene in cyclohexane at $1 \ \mu g/g$. An ovalene sample of approximately 10^{-7} M concentration, which was embedded in a polymethylmethacrylate matrix, also was analyzed periodically. These results indicated the wavelength accuracy to be ± 1.0 nm.

Scans were performed using a 0.5 nm step interval with a 0.75 second integration time at each step. This scanning procedure was equivalent to a scan speed of 40 nm/minute. Slit widths used for emission and synchronous scans were 1.25 mm (bandpass = 4.5 nm) and 0.5 mm (bandpass = 0.9 nm) for excitation and emission monochromators, respectively. For excitation scans, the slit widths were reversed. These slit widths were used throughout unless otherwise stated.

Room temperature spectra were collected using a standard 10 mm quartz cell. Optical dewars and fluorescence-free fused silica sample tubes, used for work at liquid nitrogen temperatures, were obtained from SPEX. Emission spectra were excited for most samples at 254 nm, using an excitation wavelength of 230 nm if the sample appeared to be a lighter fuel (e.g., JP-4 jet fuel). An excitation wavelength of 270 nm was used for Aroclors[®]. The emission scan was then collected from 280 nm to 600 nm. Synchronous spectra were collected by scanning both monochromators with a $\Delta \lambda$ of 25 nm and collection emission data from 275 nm to 625 nm. Excitation scans were performed by detecting at the wavelength corresponding to the strongest emission peak and scanning the excitation wavelength.

The solvent background first was subtracted from the sample spectra and the spectra then was normalized to make the maximum peak equal to one. This tended to remove any variability in spectral area arising from different emission intensities or minor concentration effects for different samples. From these normalized spectra, maximum peaks, secondary peaks, peak shoulders and spectral areas were determined. By comparing spectra digitized every 2 nm for a total of 160 points (for emission spectra) or 175 points (for synchronous spectra) to a similar vector in ndimensional hyperspace, angles between vectors were calculated for classification purposes.

Instrumental Conditions—FT-IR

A Digilab FTS 60 FT-IR spectrometer was used to collect all infrared data. The instrument used a Michelson interferometer with a beam splitter consisting of a Ge film on a KBr substrate. The source was a high temperature water cooled element, and the detector was a deuterated triglycine sulfate pyroelectric bolometer (DTGS). The spectrometer was interfaced to a Digilab 3200 Data Station with a 40 Mbyte Winchester disk and was programmable in C. All spectra were collected using a resolution of 2 cm^{-1} with 64 scans, a scan speed of 5 kHz and a low pass filter of 1.12 kHz. Instrument calibration was checked by running a polystyrene film and checking peak positions. Peak wavenumber accuracy was found to be $\pm \text{ cm}^{-1}$ over the entire spectrum.

Chemicals and Oils

Solvents used were all spectroquality or purer. Acetone and dichloromethane were obtained from Mallinckrodt (SpectAR[®]), cyclohexane from Burdick and Jackson (high purity) and methylcyclohexane from Baker (Photrex[®]). Aroclor[®] (Monsanto Co.) standards were obtained from Chem Services, Inc. The anthracene used for fluorescence calibration was from Aldrich (99.9%). The ovalene plastic standard also used for fluorescence calibration was from Starna Cells, Inc.

Reference oils were obtained from the Environmental Protection Agency (EMSL-Cincinnati), Oak Ridge National Laboratory (Martin-Marietta) and the U.S. Coast Guard Research and Development Center. Reference oils were chosen to include representative samples from the principal types of petroleum oils (light fuels, heavy fuels and crudes).

PATTERN RECOGNITION

Spectra of petroleum oils usually can be classified by a trained observer using the simple overlay method and visually comparing the closeness of match. In order to compare and classify spectra more objectively, systematic mathematical approaches have been developed.^{5, 39, 40} Various factors such as peak wavelengths, peak ratios, spectral areas and angular distances (or angles) between spectra regarded as vectors in n-dimensional hyperspace were utilized. Peak positions and vectors in n-dimensional space can be applied to both fluorescence and infrared spectra, with peak ratios playing an important role in characterization by infrared spectroscopy. Spectral areas were reserved for use with fluorescence spectra because there are fewer distinct fluorescence peaks as opposed to infrared making the total spectral envelope of more importance for fluorescence spectra.

A spectrum can be considered a vector in n-dimensional space corresponding to n-digitized intensity values of the spectrum. Two spectra with identical intensities at each digitized point over the same spectral range can be considered identical, corresponding to an angular distance in n-dimensional space of zero. Consequently, as the difference in spectral structure increases, the angle between vectors increases. The angle between two vectors X and Z can be defined as:

$$\theta_{\mathbf{x},\mathbf{z}} = \arccos \mathbf{X} \cdot \mathbf{Z} \quad \frac{\mathbf{X} \cdot \mathbf{Z}}{\mathbf{\overline{X}} \quad \mathbf{\overline{Z}}}$$
(1)

This approach was used successfully for fluorescence and infrared spectra on the weathering effects of petroleum oils by Killeen, *et al.*^{5, 34, 39} A similar approach comparing two other similarity measures was used by Sogliero and Eastwood^{7, 8} for hazardous chemicals. Since members of a class of oils or chemicals are spectrally similar, such an approach can be used for classification, for forensic identification or for estimating weathering effects.

Using these criteria, peaks corresponding to maximum intensity, areas of spectra normalized as described previously and classifying unknown oils to appropriate spectral libraries of known reference oils by angles in n-dimensional space have been utilized for emission and synchronous spectra. Data are summarized in the Results section.

SAMPLE PREPARATION

Fluorescence—Reference Oils

Standard solutions were prepared from the reference oils at a

concentration of 20 μ g/g.⁹ This sample preparation was done by diluting 1.6±1 mg of the oil to 100 mL with cyclohexane. Low actinic volumetric flasks were used to prevent photodecomposition. All samples were analyzed within 5 hr of preparation. For low temperature luminescence, spectroquality methylcyclohexane was used as the solvent. Methylcyclohexane was used because it forms a clear glass at liquid nitrogen temperatures (77 °K).^{3, 24}

Aroclor[®] Reference Solutions

Aroclor[®] reference solutions, for PCB analysis, were prepared by appropriate dilutions to concentrations of 10-30 μ g/g, using cyclohexane at room temperature of methylcyclohexane at low temperature.

Samples-Oils

Real world samples obtained for analysis were divided into three basic groups: neat samples that appeared to be pure oils; soil samples; and liquid samples (many containing a water phase) that were not pure oils.

Neat samples, those considered to be single phases, were prepared identically to the reference standards. The samples were diluted to 20 μ g/g with cyclohexane in low actinic volumetric flasks and treated as stated above.

Soil samples were extracted with cyclohexane using 10 grams of soil and 20 ml of cyclohexane with a 30 min extraction period with stirring. This solution then was filtered through glass filter paper (Whatman glass microfiber filters 934-AH) which had been prerinsed with solvent. If necessary, the solution concentration was adjusted to bring the oil concentration into a range where the sample and references spectra would be comparable.

Liquid samples that did not fall into the neat oil category were visually examined to determine the primary constituent. If an oil layer was obvious, it was removed and a 20 μ g/g solution was prepared as with the neat oil samples. If no oil was visually apparent, the sample was scanned to determine if the levels of oils were above detection levels. Where the sample showed no obvious fluorescence, the sample was extracted with cyclohexane and the organic portion was re-examined. Occasionally, a sample contained no apparent oils but did show evidence of other fluorescing species such as dyes. The excitation and emission wavelengths corresponding to peak maxima for the excitation and emission spectra were then determined and spectra analyzed for each. Literature^{21, 22, 24} was then consulted to determine the unknown.

Aroclor[®] Soil Samples

Soil samples were extracted with cyclohexane followed by treatment of the filtrate with an equal amount of concentrated sulfuric acid. This degrades oils and other possible interfering fluorescing species also extracted from the soil. The emission spectrum was then obtained by exciting at 270 nm.

FT-IR Oil Spectra

Reference oils were analyzed using a demountable cell with KBr windows and a 0.05 mm Teflon spacer. Samples then were scanned under the conditions noted under the instrumental conditions section over the range of 4000 cm^{-1} to 500 cm^{-1} .

RESULTS

Fluorescence/Luminescence

Use of fluorescence spectroscopy for forensic identification and classification of petroleum oils was proposed by Lloyd^{17,18} and has since been used by Eastwood,^{1-3, 5, 6} Vo-Dinh²⁰ and others.¹¹⁻¹⁶ ASTM methods have been developed for identification. Eastwood review article' lists many earlier references for oil fluorescence. The oil classification method used in this paper is based on a modification of ASTM method D3650-78° designed for forensic identification of water-borne oils. It assumes that a sufficient library of corrected fluorescence spectra of reference oils is available or can be generated in-house.

Twenty-nine reference oils were studied primarily by emission spectra excited at 254 nm or 230 nm and also by synchronous emission spectra ($\Delta \lambda = 25$ nm). In addition, published and unpublished spectra generated under similar conditions were available for comparison. It was known that low temperature luminescence spectra^{1, 3, 24} would yield additional spectral structure if needed.

Tables 1 and 2 list the important spectral features for emission and synchronous spectra for the 29 reference oils used in this study. These features include maximum peak wavelengths, wavelengths for secondary peaks and shoulders and the relative area under the normalized spectral envelope. Table 1 shows that spectra of diesel fuels and No. 2 fuel oils are structurally similar and that the heavier oils (No. 6 fuels and crudes) also tend to be similar to each other. Fig. 1 represents a typical No. 2 fuel oil and a typical No. 6 fuel oil. In this case, the special differences are obvious, thus allowing easy classification.

Fig. 2 shows two No. 6 fuel oils with slight emission spectral differences. Fig. 3 shows a Prudhoe Bay crude oil that has analogous spectral features to the No. 6 fuels in Fig. 2. Such close correspondence in emission spectra is very common and thus can lead to classification errors. Fig. 3 presents two crude oils that do have obvious spectral differences. The South Louisiana crude is a lighter crude than the Prudhoe Bay crude and, therefore, has its maximum peak at a shorter wavelength corresponding to a higher proportion of low molecular weight aromatics.

As mentioned above, this ambiguity between emission spectra of No. 6 fuels and some crudes may lead to classification errors. Table 2 and Fig. 4 through 6 (which show the same oils as Fig. 1 through 3) indicate that synchronous emission spectra can provide more spectral structure than the more commonly used emission scans, therefore providing more structure for spectral classifications. Of particular interest is the difference between the maximum peak wavelengths of the No. 6 fuel oils in Fig. 5 and the Prudhoe Bay crude in Fig. 6. This difference has increased to approximately 50 nm in the synchronous spectra where, as in the emission spectra, the maximum peak positions were identical. Thus, emission spectra often are sufficient to differentiate between dissimilar oil types, but a more definitive classification may be made in conjunction with synchronous spectra.

Fig. 7 through 10 provide real world examples comparing unknown oil samples with known samples in our spectral library. Fig. 7 shows that extraction from soil by the method given in this paper yields recognizable spectra. Fig. 8 shows a water sample analyzed directly without sample preparation which is comparable to a No. 2 fuel oil. Fig. 9 is interesting because it compares a real world sample with JP-4 jet fuel less commonly analyzed by fluorescence and potentially more subject to weathering. Fig. 10 shows a close correspondence between a known Prudhoe Bay Crude oil with an unknown real world sample which was received in isopropyl alcohol.

When the oils are more extensively weathered or when the classification of the oil is less clear, a more quantitative approach may be necessary. Weathering effects on fluorescence spectra of weathered oils have been described in previous papers including ASTM method 3650-78 and papers by Eastwood¹⁻³ and Killeen^{5, 39} and have indicated that fluorescence spectra of oils (after weathering in a thin film or water) are still distinguishable for identification purposes after periods from 2 days (for No. 2s) to 2 weeks or even longer (for No. 6s).

Killeen, et al.³ proposed a pattern recognition approach which allowed the possibility of correcting fluorescence spectra for weathering, given weathering data on a similar oil. This approach

Table 1
Fluorescence Spectra: Emission Characteristics of Typical
Petroleum Oils ¹

Table 2
Fluorescence Spectra: Synchronous Emission ¹ Characteristics
of Typical Petroleum Oils

WAVELENGTH (nm)

SHOULDERS (SH) (±1 nm)

317,349(SH)

323,349(SH)

306,346(SH)

306,347 (SH)

326,348(SH)

431,438,463

306,346,383,403

309(SH),345,381,411

313,330,362,383, 447(SE),487(SE),505, 516

315,331,346,360,383, 411,446,490(SH),505, 516

330,347,353,378(SH), 413(SH)

310,330,348(SH),356 381(SH),406,448,476, 492(SH),505,515(SH)

312,328,366,383, 408(SH),447,476,492(SH) 505,516

314(SH),366(SH),382 430(SH),447,463,492(SH)

315(SH),329,347(SH) 362,381,410(SH),430, 447,463(SH),482(SH) 505,516

316,334(SH),381,398, 418,446(SH),476, 491(SH),505,516(SH)

314(SH),345,360,381 409,430,446,463,492(SH) 505,516

408(SH),448,476,492(SH) 505,516

314,334(SH),382 404(SH),417,447,492(SH) 505,516

315,331(SH),382,418 447,492(SH),505,516(SH)

312,330,382,417,447

492,505,516(SH)

314 (SH) ,368 (SH) ,383 447 ,462 (SH) ,477 ,492 505 ,516 (SH)

310,329,364,383

311,330,366,383

408(SH),447(SH),476 492,505,516

316(SH),329,384, 409(SH),447,476 492(SH),506,516

312,328,365,383 408(SH),448,477,492 505,516

505,516

323

SECONDARY PEAKS,

NORMALIZED

AREA

69.0

68.9

77.7

70.7

72.4

75.7

70.9

170

262

238

166

286

249

254

219

232

222

227

222

216

271

251

242

231

258

LAB NO.	TYPE	WAVELENGTH (nm) PRIMARY PEAK (<u>±</u> 1 nm)	WAVELENGTH (nm) SECONDARY PEAKS, SHOULDERS (SH) (<u>1</u> 1 nm)	NORMALI ZED AREA	LAB NO.	TYPE	WAVELENGTH (nm) PRIMARY PEAK (<u>+</u> 1 nm)
101	JP-4 FUEL ⁽²⁾	328	337	79.8	101	TD-4 FUET	
102	DIESEL FUEL	314		86.4	102	DIESEL MET.	325
103	DIESEL FUEL	311	324 (SH) ,352(SH)	116	102	DIESEL FUEL	312
104	DIESEL FUEL	307	324 (SH)	97.4	104	DIESEL FUEL	324
105	DIESEL FUEL	307	324(SH),349,382,404	122	105	DIESEL FUEL	324
106	NO.2 FUEL	308	323 (SH)	101	106	NO.2 FUEL	325
107	NO.2 FUEL	308	313(SH),352,369	102	107	NO.2 FUEL	316
108	NO.4 FUEL	355	308,324,407,440(SH)	241	108	NO.4 FUEL	325
109	NO.6 FUEL	358	314,374,402(SH), 444(SH)	233	109	NO.6 FUEL	419
110	NO.6 FUEL	357	316,374,407,444(SH)	218			
ш	NO.6 FUEL 0.34 SULFUR CARIBBEAN PRO	356 DUCT	314,345(SH),371(SH)	160	110	NO.6 FUEL	417
112	NO.6 FUEL LOW SULFUR	357	314,372,445(SH)	215	111	NO.6 FUEL 0.3% SULFUR CARIBBEAN PRODU	311 XCT
113	NO.6 FUEL	357	315,374,454	234			
114	NO.6 FUEL MED. SULFUR	356	314,372,451	232	112	no.6 Fuel Low Sulfur	418
115	NO.6 FUEL 2.94 SULFUR DOMESTIC PRODUCT	364	315(SH),376,408,446	270	113	NO.6 FUEL LOW SULFUR	420
116	NO.6 FUEL HIGH SULFUR	357	315,375,404,442(SH)	246	114	NO.6 FUEL MED. SULFUR	421
117	NO.6 FUEL HEAVY	362	316,364,405(SH),453	295	115	NO.6 FUEL 2.9% SULFUR	417
118	NO.6 BUNKER	359	315,373,444(SB)	212		PRODUCT	
119	BUNKER FUEL	357	315(SH),378,408, 440(SH)	232	116	NO.6 FUEL HIGH SULFUR	416
120	BUNKER C RESIDUAL	363	316(SH),378,407,451	286			
121	ARABIAN LIGHT CRUDE	356	312,372,448	231	117	NO.6 FUEL HEAVY	417
122	Arabian, Safaniva Heavy Crude	358	313,372,453	261	118	NO.6 BUNKER	363
123	California, Kern River Crude	358	315,375,447	222	119	BUNKER FUEL	415
124	CALIFORNIA, WILMINGTON CRUDE	357	315,373,445(SH)	211	120	BUNKER C RESIDUAL	417
125	iranian heavy Crude	358	315,373,453	217	121	ARABIAN LIGHT CRUDE	418
126	NORTH SLOPE Alaska Crude	357	315,368,445(SH)	193	122	ARABIAN, SAFANIVA	417
127	PRUDBOE BAY CRUDE	357	315,372,445(SH)	212	123	HEAVY CRUDE	363
128	South Louisiana Crude	357	313,326 (SH),346 (SH) 374,445 (SH)	232		KERN RIVER CRUDE	
129	WYOMING, RECLUSE CRUDE	357	313,371(SH)	199	124	CALIFORNIA, WILMINGTON CRUDE	363
⁽¹⁾ Encit	ed at 254 nm ex	cept where indicat	ed		125	IRANIAN HEAVY CRUDE	363

(1) Bucited at 254 nm except where indicated

⁽²⁾Excited at 230 nm

TABLE 2 (con't.)

LAB NO.	TYPE	WAVELENGTH (nm) PRIMARY PEAK (<u>+</u> 1 nm)	WAVELENGTH (nm) SECONDARY PEAKS, SHOULDERS (SH) (±1 nm)	NORMALI SEL AREA
126	NORTH SLOPE Alaska Crude	360	313,328,381(SH), 401(SH),417,446(SH), 492(SH),505,516(SH)	240
127	PRUDHOE BAY CRUDE	360	312,328,382(SH) 401(SH),417,446(SH), 492(SH),505,516(SH)	245
128	South Louisiana Crude	312	327 , 348 , 382 (SH) , 406 (SH) , 418 , 436 (SH) 447 (SH) , 463	178
129	WYOMING RECLUSE CRUDE	327	309 , 347 , 354 (SH) 359 (SH) , 380 (SH) , 406 (SH) 417 , 447 (SH) , 492 (SH)	215
(I)				







Emission spectra of a No. 2 fuel oil, Lab No. 106 (solid line_____) and a No. 6 fuel oil, Lab No. 109 (dashed line ---). Both 20 µg/g in cyclohexane. Excited at 254 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.









Emission spectra of South Louisiana Crude (solid line _____), and Prudhoe Bay Crude (dashed line ---). Both 20 µg/g in cyclohexane. Excited at 254 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.



Figure 4



uses spectra of weathered and unweathered oils considered as ndimensional vectors in hyperspace (where n is the number of digitized points). These spectra then can be used to generate a weathering surface in hyperspace, and angles between vectors can be calculated to estimate weathering effects.

In this paper, an approach similar to the one discussed in the Pattern Recognition section is used to determine if an unknown oil belongs to the same class as a known reference oil. As seen in Tables 3 and 4, $\theta = 0.0$ is equivalent to identity. Allowing for weathering effects, experimental error and computer rounding error, spectra within $\theta = 0.005$ might still represent the same oil. Oils of the same class might reasonably be expected to agree to within 0.15. Table 3 shows the search of a No. 2 fuel oil against the entire emission library. The similarity between No. 2 fuels oils and diesel fuels can readily be seen. In some cases it may be necessary to include the wavelength of the maximum peak and the peak



Wavelength (nm)

Figure 5

Synchronous spectra of a No. 6 fuel oil, low sulfur, Lab No. 113 (solid line _____), and a No. 6 fuel oil, Lab No. 110 (dashed line ---). Both 20 μ g/g in cyclohexane. Both monochromators scanned simultaneously with a $\Delta \lambda$ of 25 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.





area. As indicated in Table 4, it may be necessary to include the angles between the synchronous spectra to more readily distinguish between No. 6 fuel oils and crude oils. Table 5 shows the results of a library search using the spectrum of a real world sample (Fig. 10) and the degree of match with reference oil spectra.

Fluorescence/Luminescence-Hazardous Chemicals Including PCPs

A 1979 U.S. Coast Guard report by Brownrigg, et al.,²² listed approximately 90 hazardous chemicals from the U.S. EPA HSL list and the U.S. DOT CHRIS list which could be readily identified by their room temperature fluorescence spectra (now the basis for a draft ASTM method). By including low temperature luminescence/phosphorescence spectra, this list could be extended to include approximately 250 hazardous-chemicals.

Sogliero and Eastwood^{7, 8} used pattern recognition techniques

 Table 3

 Computer Search of Emission Spectrum of No. 2 Fuel Oil

 (Lab No. 107) Against Emission Library (5 Best Matches)

LAB NO.	ТҮРЕ	MAX PEAK(nm) (<u>+</u> 1 nm)	NORMALIZED AREA	Angular* Distance (Radians)
107	NO.2 FUEL	308	102	0.0000
103	DIESEL FUEL	311	116	0.0954
106	NO.2 FUEL	308	101	0.0964
104	DIESEL FUEL	307	97.4	0.1099
102	DIESEL FUEL	314	96.4	0.1430

*160 DIMENSIONAL VECTOR

Table 4Comparison of Searches Between Emission (Table 1) andSynchronous (Table 2) Libraries, for Kern River, California Crude Oil(5 Best Matches)

EMISSION

LAB NO.	TYPE	MAX PEAK (מת) (<u>+</u> 1 מת)	NORMALIZED AREA	ANGULAR ⁽¹⁾ DISTANCE (RADIANS)
123	CALIFORNIA KERN RIVER CRUDI	356 E	222	0.0008(2)
118	NO.6 BUNKER	359	212	0.0482
124	CALIFORNIA WILMINGTON CRUD	357 3	211	0.0708
109	NO.6 FUEL OIL	358	233	0.0754
110	NO.6 FUEL OIL	357	218	0,0841

	SYNCHRONOUS					
LAB NO.	TYPE	MAX PEAK (חמת) (<u>+</u> 1 חמת)	NORMALIZED AREA	ANGULAR ⁽³ DISTANCE (RADIANS)		
123	CALIFORNIA KERN RIVER CRUDI	363	242	0.0005(2)		
118	NO.6 BUNKER	363	227	0.0478		
124	CALIFORNIA WILMINGTON CRUDI	363 2	231	0.0619		
125	IRANIAN HEAVY CRUDE	363	258	0.0722		
127	PRUDHOE BAY CRUDE	360	254	0,1958		

⁽¹⁾160 Dimensional Vector

(2) Note computer rounding error

(3) 175 Dimensional Vector

and similarity measures such as angle between spectra as n-dimensional vectors in hyperspace, Euclidean distances and correlation coefficient on a library of about 60 low temperature luminescence spectra of hazardous chemicals.

Earlier work by Brownrigg and Hornig²² showed that low temperature luminescence spectra could distinguish PCBs from DDT. In this study, only PCBs (Aroclors[®]) have been used as an example of hazardous chemicals for which fluorescence/luminescence techniques should be useful. Fig. 11 shows a comparison of PCBs at 77 °K where the emission intensity is greater for phosphorescence than fluorescence so that greater sensitivity (allowing quantitation to a few ppb) is achieved using low temperature luminescence. For field screening at the ppm range,



Wavelength (nm)

Figure 7

Emission spectra of a real world sample extracted from soil with cyclohexane (solid line _____), and a No. 2 fuel oil, 20 µg/g in cyclohexane (dashed line ---). Excited at 254 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.



Figure 9



room temperature fluorescence appears satisfactory, since fluorescence quenching by the internal heavy atom effect is not complete. Fig. 12 shows room temperature fluorescence spectra of a real world comparison of Aroclor^{\oplus} 1254 with a real world sample extracted from soil and treated with sulfuric acid. This sample then was analyzed by GC methods and found to contain 15 ppm of Aroclor^{\oplus} 1254. This indicates that PCBs can be measured by fluorescence even in the presence of an oil background.

FT-IR

FT-IR results will be discussed only briefly, since infrared techniques for oils have been explored for identification by Brown^{27.33} and others,^{6, 34} and a study by Grant and Eastwood⁴ has dealt with classification of natural oil seeps and California production oils by a field infrared unit. Similarly, the potential of FT-IR and



Emission spectra of a real world sample in aqueous solution, concentration unknown (solid line _____), and a No. 2 fuel oil, 20 µg/g in cyclohexane (dashed line ---). Excited at 254 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.



Figure 10

Emission spectra of a real world sample in isopropyl alcohol, concentration unknown (solid line _____), and Prudhoe Bay Crude, 20 µg/g in cyclohexane (dashed line ---). Excited at 254 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.

GC-FT-IR for identification and classification of hazardous chemicals has been extensively explored by Griffiths,³⁴ Gurka³¹ and others.³⁵⁻³⁷

Fluorescence and infrared methods for petroleum oils yield similar results for forensic identification. In rare cases when it was necessary to discriminate between closely similar oils, not the case for classification, low temperature luminescence,¹⁻³ which generally provides sharper spectral structure than room temperature fluorescence, was found to yield pattern recognition results similar to infrared spectroscopy.

In the present study, it was necessary to employ infrared techniques in cases when fluorescence spectra indicated that the hazardous waste sample was not a typical oil or was heavily contaminated with non-oil material. Although IR, GC-FT-IR or GC-MS techniques often were used for confirmation at typical oil or PCB



Wavelength (nm)

Figure 11





Figure 12

Emission spectra of a real world sample extracted from soil with cyclohexane and H₂SO₄ (solid line _____), and Aroclor[®] 1254, 27 µg/g in cyclohexane (dashed line ---). Excited at 270 nm. Excitation bandpass, 4.5 nm. Emission bandpass, 0.9 nm. Backgrounds subtracted out.

sites, they usually were unnecessary.

Two examples of typical FT-IR oil spectra are included. Fig. 13 compares the FT-IR spectra of No. 2 and No. 6 fuel oil from $2000 - 500 \text{ cm}^{-1}$. Note that the 900-700 cm⁻¹ region, the so-called fingerprint region, has been particularly indicative of oil type and relatively unchanging with weathering. Fig. 14 compares similar reference spectra for a Prudhoe Bay crude oil and a South Louisiana crude oil. Earlier studies by Brown and others²⁷⁻³⁴ have addressed likely changes in reference spectra (peak positions and peak ratios) due to weathering and have proposed artificial weathering or knowledge of the weathering history for similar oils as a method of compensating for these effects.

In Table 6, peak positions for the oils in Fig. 13 and 14 are listed for the peaks previously selected by Brown and others²⁷⁻³⁴

 Table 5

 Computer Search of Emission Spectrum of Real World Sample (343)

 Against Emission Library (5 Best Matches)

LAB NO.	TYPE	NAX PEAK(ma) (±1 ma)	NORMALISED AREA	Angular* Distance (Radians)
	REAL WORLD SAMPLE 343	357	209	
127	PRUDHOE BAY CRUDE	357	212	0.0764
126	NORTH SLOPE ALASKA CRUDE	357	193	0.0903
121	ARABIAN LIGHT CRUDE	356	231	0.0931
125	IRANIAN HEAVY CRUDE	358	217	0.1045
114	NO. 6 FUEL MEDIUM SULFUR	356	232	0.1131

*160 DIMENSIONAL VECTOR

Table 6
List of Wavenumbers Used in Computer Analysis of Infrared Spectra
(To Nearest 5 CM ⁻¹)

720	780	835	955
725	790	845	1020
745	805	870	1070
765	810	890	1145
770	820	915	1160

 Table 7

 Aromatic-Aliphatic Peak Intensity Ratios for Infrared Peaks

 747 CM ⁻¹ and 725 CM ⁻¹

LAB NO.	TIPS	ARMATIC/ALIPHATIC RATIO*
106	NO.2 FUEL	1.33
110	NO.6 FUEL	1.34
127	PRUDBOE BAY CRUDE	1.07
128	SOUTH LOUISIANA CRUDE	0.737
*Peak at	747 cm^{-1} corresponds to (-H ammetic

Peak at 725 cm corresponds to C-H alighatic

Table 8 Computer Search of FT-IR Spectra of Prudhoe Bay Crude Against Typical Oil Types

LAB NO.	TYPE	ANGULAR DISTANCE (1) (RADIANS)		
127	PRIDHOE BAY CRUDE	0.0010 ⁽²⁾		
106	NO.2 FUEL	0.1819		
110	NO.6 FUEL	0.1997		
128	SOUTH LOUISIANA CRIDE	0.3551		

(1) 20 DIMENSIONAL VECTOR

(2) NOTE COMPUTER ROUNDING ERROR



Figure 13 FT-IR spectra of No. 2 and No. 6 fuel oils. Resolution was 2 cm⁻¹ with 64 scans. KBr windows with a 0.05 mm Teflon spacer were used.



FT-IR spectra of Prudhoe Bay and South Louisiana Crudes. Resolution was 2 cm⁻¹ with 64 scans. KBr windows with a 0.05 Teflon spacer were used.

as useful for oil identification by infrared. In Table 7, the ratio of 747 cm⁻¹/725 cm⁻¹ gives a comparison of the aromatic/aliphatic composition. This is of interest primarily for comparison to the fluorescence spectra which characterizes the aromatic fraction of the oil or fluorescent hazardous chemicals containing aromatic or heterocyclic ring systems.

For pattern recognition purposes, the greater spectral structure and greater ease in infrared interpretation of infrared peaks in terms of vibrations of known structural components (group frequencies) plus the large infrared libraries of hazardous chemicals available make more elaborate pattern recognition schemes relatively unnecessary. Although spectral areas and angles between n-dimensional vectors can be given, they are needed less for classification purposes than in the case of fluorescence. The use of oil classification by angles between spectral vectors is illustrated in Table 8.

CONCLUSIONS

Fluorescence/luminescence spectroscopy has been used successfully for screening, detecting, classifying and semiquantitating real world DOD samples containing petroleum oils, petroleum-based fuels and solvents and PCBs in a variety of sample matrices (water, soil, sludge and bulk chemicals). By supplementing fluorescence techniques with FT-IR, where necessary, for confirmation and to detect non-aromatic or non-fluorescing components, these complementary techniques can form a powerful analytical tool for screening and classifying hazardous chemicals in a variety of environmental wastes. These techniques potentially can be applied to a broader range of hazardous chemicals under field conditions.

Appropriate in-house reference libraries of petroleum oils are being developed. Pattern recognition techniques for both fluorescence and FT-IR spectra have been developed. For fluorescence (emission and synchronous), useful parameters included maximum peak positions, areas under the spectral envelope of the normalized spectra and angles between appropriate spectra where spectra are treated as n-dimensional vectors. For FT-IR, pattern recognition techniques included peak positions (for 20 major peaks), a peak ratio to indicate the aromatic/aliphatic character of the oil and angles between spectra treated as 20-dimensional vectors.

In the future, we plan to expand spectral libraries for reference petroleum oils and fuels and hazardous chemicals analyzed on in-house instrumentation by both fluorescence and FT-IR. A better classification scheme for oil spectra including subclasses based on spectral characteristics rather than just API categories or physical properties could be developed. Classification schemes related to the geographical origin of oils also may be of interest.

Different chemometric or pattern recognition approaches may be applied, including use of similarity measures such as correlation coefficients or Euclidean distances, Fourier transformations or sine and cosine series.

Preliminary measurements on PCBs need to be expanded and refined to allow better detection, identification and quantitation of these ubiquitous chemicals even in the presence of oils. Studies of other important classes of fluorescing hazardous chemicals such as phenols, organochlorine pesticides, dioxins and PNAs are needed.

Better quantitation procedures for oils by fluorescence are needed. Better field procedures are required, especially for PCBs, pesticides and DDT. Exploration of techniques such as room temperature phosphorescence and remote fiber optics also are planned.

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Toxic Gas Collection and Treatment System At an Uncontrolled Superfund Site

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ABSTRACT

A toxic gas collection and treatment system was installed on an emergency basis at the uncontrolled landfill Superfund site in Gloucester Township, New Jersey. Monitoring at the site indicated that a mixture of combustible and toxic gases was moving toward two residential areas built near the toe of the landfill. The New Jersey Department of Environmental Protection (NJDEP) became concerned about the combustibility and toxicity of these gases as they continued to migrate toward the homes. When monitoring data began to indicate combustible levels approaching the lower explosive limit near the homes, the NJDEP decided that action should be taken to install a gas collection and treatment system.

Problems that are presently being resolved include:

- Fail-safe systems to prevent liquids from reaching the blower
- Monitoring exhaust gases from the present treatment unit to determine if further treatment is necessary.

Toxic dangerous chemicals included methane gas, benzene compounds, xylene and toluene. Numerous other compounds were present at lesser levels.

INTRODUCTION

During the period beginning Oct. 22, 1985 and ending Jan. 24, 1986, S&D Engineering Services was engaged in the fabrication, installation and erection of a gas recovery and treatment system at the GEMS Superfund site under the direction of the New Jersey Department of Environmental Protection (NJDEP). Upon completion of the construction phase of the work, S&D Engineering Services provided operations and maintenance services for the collection and treatment system as directed by the design engineer and the NJDEP.

The system consists of 32 wellpoints installed in two locations designated "Site A" and "Site B" and consisting of 14 and 18 wells, respectively. The wells are connected by 8-in. schedule 40 PVC piping designated "Header A" and "Header B", respectively. A 10-in. PVC pipeline extends from the treatment plant to header B and connects it to the system. A 2000 ft³/min positive displacement pump is connected to the system which draws the gas and air mix from the soil and groundwater and passes it through an activated carbon treatment system and thereafter out through a 20-ft high exhaust stack.

PROBLEM DESCRIPTION

The Gloucester Environmental Management Services (GEMS) Landfill had operated for more than 20 yr. Prior to 1974, organic solvents and other industrial chemicals were disposed of in areas below the groundwater table. Preliminary geophysical investigations conducted by the Department's Division of Water Resources indicated that the landfill is the cause of surface and groundwater contamination. Volatile organic chemicals have been detected in monitoring wells, private wells, leachate and stream samples.

The GEMS Landfill is located in Gloucester Township, New Jersey. The residences closest to the landfill are in two small developments off Erial Road; namely Fox Chase II and Holly Run Road (see Fig. 1). Holly Run is a small stream that is located between these residences and the landfill. The site has been studied by the NJDEP, the U.S. EPA Technical Assistance Team (TAT) and the NUS corporation.

Much of the previous investigation of the site has focused on groundwater. However, this work addressed the soil-to-air emissions and the migration of hazardous gases through the soil and the groundwater.

Previous studies identified some of the organic gases in the soil. The principal gas is methane which is generated through municipal decomposition; however, volatile organic compounds (VOCs) also were found in the gas phase in the soil.¹

Samples were taken in the general vicinity of the residential housing developments. The data show significant concentrations of gases in the area between Fox Chase II and the landfill. Levels ranged up to 100% Lower Explosive Limit (LEL). VOCs were found in the gas from these areas at concentrations of 1.0 to 48.6 ppm. Neither methane gas nor VOCs were detected north of Erial Road. In the remaining areas investigated, levels of organics were not as high and dropped off rapidly as the distance from the landfill increased. As a result of these findings, remedial measures were developed to reduce gas migration from the landfill.

Compounds found in the ambient air at the site include toluene, benzene, ethylbenzene, chlorobenzene and xylenes. Some of the highest concentrations were found along Erial Road and along Holly Run.

Soil gases were measured by extending a borehole about 4 ft into the ground and sampling the borehole air. Contaminants found in the soil gas samples included 1,2-transdichloroethene, trichloroethene, xylene, benzene, toluene, ethylbenzene, chlorobenzene and styrene. Details of these data are available in other reports.^{1,2}

The conclusions from both of these previous investigations that are most relevant to the emergency situation are:

- Methane gas contaminated with volatile organics was migrating from the landfill face parallel to Erial Road in the vicinity of the Holly Run Road residences in concentrations greater than 100% of the LEL. Volatiles were detected at 49 ppm.
- Methane gas contaminated with volatile organics was migrating

from the landfill face parallel to Erial Road in the vicinity of Fox Chase II development in concentrations exceeding 100% of the LEL. Analysis of the soil gas from the backyard of one of the residences confirmed the presence of methane gas migrating from the landfill.

• The residential area between Holly Run Road and the intersection of Erial Road and Hickstown Road was the site of one sample, and this showed no detectable levels of either methane gas or volatile organic compounds.

It was evident that methane gas existed in the area at concentrations greater than the LEL. While not usually a hazard in the soil, under certain atmospheric conditions this gas could create an explosive mixture if allowed to accumulate in a confined space such as a basement. This gas was contaminated with detectable and significant quantities of volatile organic compounds composed primarily of benzene, toluene and ethylbenzene, with lesser amounts of chlorobenzene and dichlorobenzene.

It was the opinion of the NJDEP that there may be an explosion hazard to the residences of the Fox Chase II development and those on Holly Run Road but not to those north of Erial Road. This situation presented a health and safety risk to those on-site and near the site in the areas of concern.

REMEDIAL ALTERNATIVES

As a result of these findings, two remedial actions that addressed gas controls for hazard elimination at the affected residences were considered.² These were:

- Induced draft pipe vents with a collection system and gas treatment system
- Induced draft closed trench vent with an integral collection system and gas treatment system

Induced Draft Pipes

An induced draft pipe vent collection system consists of four main parts:

- Pipe vents in and/or around landfill surface
- Collection system with fittings and balancing valves
- Fan or blower to provide driving force on vents
- Pressure Measuring device before and/or after the fan or blower

In addition, provisions for moisture collection, access ports and allowances for differential settlement of the header pipe system need to be considered and incorporated into the design of the system. The vent pipes are installed at appropriate intervals dependent upon subsurface soil conditions to collect all gas and not allow any migration past the vent line. The vent is usually about 4 to 8 in. in diameter and is surrounded by a lwyer of coarse gravel. The total diameter of the installation may vary up to 3 ft. The surface in the immediate vicinity of the vent is capped with impervious material to prevent rainwater infiltration and unwanted gas venting.

The vents are connected to an exhaust header which may be a single branch or one of a number of branches connected to a manifold and ultimately to a fan or blower that puts a negative pressure on the vent and draws out the gas. Each connection to the vent is supplied with a measuring device such as a pitot tube and/ or a control device such as a butterfly valve for balancing the system.

The final part of the vent system includes equipment for the treatment and disposal of the collected gas. The two primary treatment methods used are carbon adsorption and thermal oxidation. Given the high concentrations of VOCs found in the gas from the GEMS Landfill, it probably will be necessary to treat the gas by passing it through a carbon chamber prior to venting or flaring. The carbon scrubs the higher molecular weight volatiles from the gas stream while leaving the methane intact for subsequent venting or flaring.

Induced Draft Trench

An induced draft closed trench collection system utilizes a horizontal collection pipe in a continuous trench excavated down to either groundwater or an impervious layer. The trench is lined with a synthetic liner to eliminate gas migration and is filled with gravel to facilitate gas movement toward the collection pipe buried in the trench. This collection pipe is connected to a blower or fan for gas collection. The gas is treated and discharged in a similar fashion to the pipe vent system.

System Choice

These two alternatives were evaluated based on five criteria:

- Reliability
- Constructibility
- Implementation time frame
- Environmental effectiveness
- Cost

The pipe vent collection system scored the highest in the evaluation and was the alternative of choice for perimeter control of gas.² The gas vent specification is shown in Fig. 3; the final remedial design installed at the site is shown in Fig. 1 and 2.

THE EMERGENCY INSTALLATION

NJDEP Action

After evaluating the environmental and health concerns at the site, the NJDEP decided an emergency response was necessary. The main object was to prevent the combustible and toxic mixed gases from continuing to migrate toward the two residential areas.

New Jersey has several sources of funds to be used for remedial work at Superfund sites. These are:

- The Spill Compensation Fund—\$25,000
- The Hazardous Discharge Bond Act-\$100,000
- The Superfund Allocation for New Jersey-\$84,000

In this case, the Emergency Spill Fund was used.

A Project Officer was designated by the state. His responsibility was to select the best remedial alternative within the time and cost constraints given and select a contractor who could install the system on an emergency basis. The major constraints in descending order were:

- Protection of health and environment from the migrating gases
- Time—selection of remedial design and the installation of the system was on an emergency basis
- Cost—the emergency basis was inherently expensive, but cost savings were considered each step of the way
- Operation and maintenance—the system had to operate unattended with a minimum of maintenance

Consultant's Actions

S & DESI was called on Oct. 10, 1985 (because it was at the top of a rotational list of qualified emergency contractors for the Southern Region of the state) and was told that a gas collection system needed to be installed at the site on an emergency basis. However, a planning meeting was required to discuss the proposed design and how to implement it at the site. A result of this meeting was that the gas collection system was changed from a trench design to a collection well design. Both designs were described in the preceding section.

The main reason for changing the design was to minimize the risk of a release of explosive/toxic gases and the associated poten-

tial hazards. Installing one 6-in. diameter gas collection well at a time minimized both the risk of gas release and hazardous incident.

Health and Safety

Health and safety guidelines were established to protect both the workers and nearby residents. The main concerns were the potential releases of toxic gases above the Permissible Exposure Limit (PEL) and release of explosive gases above or near the LEL. The action level for initiating ambient gas monitoring of nearby homes for sustained levels of methane and other explosive gases was 25% of the LEL. The action level for upgrading the personal protection level was a sustained level of the toxic volatile organics of 5 ppm or the lowest PEL, whichever was determined to be lower.

On-site monitoring during the installation included the following:

- A meteorologic weather station was installed to daily record wind direction, speed, temperature and humidity
- A photoinization detector was calibrated and used to monitor for the listed volatile organics
- Explosimeters were used to monitor both methane gas and total mixed explosive gases
- Packed sampling tubes with calibrated pumps were used to obtain 7-hr samples for GC/MS analysis as required
- The ANJDEP Air Monitoring team used a PID and OVA (portable gas chromatograph) to periodically (approximately once per week) monitor in the work zone and near the residential homes

The on-site health and safety plan included an air monitoring survey using a PID; this survey was conducted prior to the commencement of work each morning. The readings found in the survey were used to determine the level of personal protective equipment to use and to confirm the level of protection needed at the various areas/zones at the site.

The NJDEP required that all personnel have medical monitoring prior to working at the site. This requirement was used to determine whether the worker (1) was physically fit for the job and could wear respirators and (2) had an existing physiological problem due to previous exposure to the types of contaminants at the site.

Contingency and emergency evaluation plans were developed for the project. The most critical safety planning elements for this site concerned what to do if explosive gases levels approached the LEL and/or toxic gas levels exceeded their PEL. Local emergency resources were contacted and included in the plan. Emergency response gear maintained at the site and near the work zones during operations included:

- SCBAs for respiratory protection
- Several class A, B, C Fire Extinguishers
- Several protein foam canisters and applicators for vapor suppression
- A portable fire pump and fire hose with long-range nozzle
- Earth-moving equipment with enclosed cabs and SCBAs to provide emergency earth coverage

The major health and safety problems encountered at the site were:

- The roadway constructed between Sites A and B involved a considerable amount of uncertainty; therefore operations were conducted in Level B protection; additional concerns were raised by several buried drums that required special cleanup and security
- The recovery well installation at Site B required a considerable

amount of Level B protection and portable communication since it was approximately 3,000 ft from Site A and the office trailer

• Several workers received temporary medical treatment for nausea due to the inhalation of normal "garbage" odors associated with most domestic landfills: methane and other toxic gases were not detectable even with an 8-hr sample analyzed with a GC/MS. We went to Level B protection for additional safety in this work area

PROBLEMS AND SOLUTIONS

Specific Problems

Difficult problems that were overcome during the installation included:

- Installing collection wells rapidly in unconsolidated materials with a near-surface groundwater table
- Maintaining a slope on the collection manifold to drain off condensate and leachate
- Allowing for collection pipe movement due to thermal effect and soils movement
- Connecting two gas collection systems located approximately 3,000 ft apart through rough terrain, forest, marsh and landfill areas
- Contending with buried drums and other hazardous waste
- Preventing possible gas ignition from occurring and moving through the system

Specific Solutions

The overall assessment of the installation project was that it was very successful. Each problem listed above was overcome. S & D Engineering Services, Inc. developed a recovery well installation technique using a large truck mounted backhoe, a front end loader and a 12-in. diameter by 25-ft long steep pipe with a 4-ft lift cable attached to one end. The backhoe dug a pit roughly 4 ft in diameter and 15 ft deep in the unconsolidated/unstable soils. This pit normally went at least 4 ft into the existing groundwater table. The steel pipe was quickly attached to the backhoe and lowered into the pit to prevent the soil from caving in. The 6-in. diameter slotted/screened PVC pipe was then installed inside the steel casing, and river gravel was packed around it using the loader and shovels. The soil was then packed around the outside of the casing and the casing was lifted vertically and removed. Using this method, up to 8 wells could be installed per day, barring unforeseen difficulties.

Much of the excavation for access roads and well installations was into parts of the landfill. This created some unpredictable health and safety problems that had to be solved. The same safety procedures stated for the general well installation technique were used here, also. In addition, an emergency response vehicle with spill response materials and drum handling capability was put on standby while working in the landfill areas per se. This response capability was used on several occasions.

One of the biggest obstacles to the completion of this project was how to connect two gas collection systems locateld approximately 3000 ft apart, through rough, forested terrain. The connecting line was to have constant slope from system B down to the system A connecting points and a minimum pressure loss. This line was successfully achieved by using 8-in, diameter PVC pipe, heavy equipment and chain saws to clear the trees and thickets and wooden mounts to elevate the pipeline and maintain the slope. With the manifold pipelines and the common collection point, all water could be drained out of the lines prior to reaching the blower.

Thermal effects on the above-ground system also were considered. The effects of thermal expansions and contractions throughout the thousands of feet of welded PVC pipes were relieved by using rubber-base connectors (Fernco[®] connectors). These connectors also allowed flexibility in routing the pipeline through the marshy woods and adjusting for elevations. Also, the vertical gas collection wells were connected to the horizontal manifold pipeline using wire reinforced rubber pipe connectors for both systems A and B.

Several potential sources of ignition were defined in the gas treat system which consisted of a gas blower (or pump) and a granulated activated carbon (GAC) unit. The gas blower was required to deliver 2000 ft³/min at 24 in. of water column pressure. However, the blower had to be an "off-the-shelf" unit since the installation was on an emergency basis. To get a unit that was non-ferrous and internally explosion-proof for the gases involved would have taken several months. So the glas blower became a potential source of gas ignition. The supplier of the GAC unit indicated that static electricity could build up and possibly ignite the gases at their LEL. To eliminate the possibility of ignited gases cascading throughout the entire system, a flame arrestor was placed both upstream and downstream of the gas blower.

Project Startup

After the installation was completed and the blower was installed and checked out electrically, the equipment was tested.

Startup procedures were carefully adhered to, especially with the blower. This included operating the unit under the no load condition for the specified period of time.

Having completed all shakedown requirements and initial startup procedures, the gas collection/treatment system was ready for commissioning. Since there was no way to be sure about the pressure drops throughout each system, we decided to open the butterfly valves to each well and the main control valve for the interconnecting line to system B only 50%. The three air inlet valves (one at each end of manifold A and one at the extremity of manifold B) were left closed. The blower was started and vacuum pressures were measured at selected wells for system A and B and the pressure drop across the blower. The Positive Displacement type blower generated much more vacuum than required at the wells, and the systems were not balanced. After considerable trial and error, the valves were adjusted to effect nearly the same vacuum in each well, and the air inlet valves were opened to allow a general lowering of the vacuum throughout the entire system.

Water Problems

Once the system was balanced and running well, we decided to let it run continuously for 24 hr. During this period, we discovered that the varying water table could have a drastic effect on the system as the level of groundwater rose to cover the slotted/ screened portions of the gas recovery wells. When this occurred, the blower would lift the water/leachate out of the well and draw it into the gas blower. The blower, not being designed for liquids, became overloaded and shut down. Fortunately, the blower was repairable and all moisture and impending rust were removed. The blower has been installed in a standby mode until the system is modified to eliminate/prevent moisture from reaching the blower.



Figure 1 Toxic Gas Treatment System



Figure 2 Toxic Gas Collection and Treatment System

System Uncertainties

Normal procedures for installing a system as complex as this at an uncontrolled site with its numerous uncertainties would require a complete and thorough study of all pertinent facts and design parameters. However, when significant health and environmental risks are so imminent, there is hardly time to follow the normal/standard operating procedures. Rather, the question becomes one of what can be done to alleviate the dangers and risks within a specified short amount of time. So time becomes the overriding specification and engineering design and specifications as well as the environmental information upon which they are based become supplemental to it. Even with the uncertainties at hand, a system was installed that had the necessary flexibility to allow it to operate adequately under continuous supervision and provide protection to the nearby residents suffering from the migrating toxic/explosive gases.

FUTURE PLANS

Future plans call for further refinement of the system to allow it to operate unattended and trouble-free. These planned modifications include the design and specification of water/moisture sensors that will be installed at various strategic points throughout the system to send early warning signals to activate an alarm and/or shut the blower off. Should the blower be shut off, an automatic telephone dial system would be activated to place an emergency call to the NJDEP and/or emergency response contractor. A preprogrammed message would be given to the recipient of the emergency call. Immediate action could be taken to restore the system to proper operation.



Figure 3 GEMS Landfill Gas Vent Detail

Also, consideration is being given to using automatic monitors for the exhaust gas. This monitoring is especially desirable if high concentrations of methane are encountered. It is fairly certain that the recovered gas concentrations will vary significantly over extended periods of time. Should significant levels of methane continue, the NJDEP will consider the installation of the ground flare system to burn-off the methane and mixed gases.

REFERENCES

- 1. U.S. EPA, "Remedial Investigation Report Volume I for Gloucester Environmental Management Services, Inc. (GEMS) Landfill Site, Camden County, New Jersey," U.S. EPA Work Assignment Number 15-2M29.0, July 1985, Chaps. 4 and 5.
- NJ Department of Environmental Protection, "Gas Migration Repolrt for GEMS Landfill Gloucester Township, New Jersey," Malcolm Pirnie, Oct. 1985.

Rapid, Cost-Effective GC Screening for Chlorinated Pesticides and Volatile Organics at CERCLA Sites

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ABSTRACT

The Region VIII REM 11 Team (CCJA/CDM) has developed an in-house analytical support program that provides rapid, costeffective screening analyses of organic contaminants in environmental samples. This program has been used to support RI/FS field activities at a CERCLA site in the Denver metropolitan area. The site manager and the project health and safety officer have used the screening data in the execution of the following activities: site characterization, decontamination procedures, monitor well screen placement and site personnel exposure monitoring.

The screening protocol for organic contaminants has been designed to meet project requirements for the semi-qualitative, semi-quantitative analysis of specific target compounds that have been identified from previous site work. For this project, the list of target compounds that are indicative of the classes of chemical contaminants (e.g., volatiles and chlorinated pesticides) that are present on-site includes: trichloroethylene, toluene, p,p-DDT and dieldrin. Additionally, relative amounts of organic contamination due to the presence of either extractable or volatile compounds may be determined. Organic compounds are detected using two portable HNu 301 gas chromatographs equipped with a PID connected in series with either an F1D or a Hall-type ECD (halogenmode). Sample preparation techniques include a hexane/acetone extraction procedure for chlorinated pesticides and either headspace or purge and trap for volatiles.

Requirements for sample cleanup and preparation are minimized using the halogen-specific detector and the headspace technique (for volatiles).

The analytical quality assurance program includes standard operating procedures for the following steps: sample collection and analysis, personnel training, sample custody, document control and data management. Laboratory quality control samples (i.e., blanks, duplicates and matrix spikes) have been analyzed at a minimum frequency of 1 per 10 samples or 1 per batch. Instrument calibration has been performed daily, and calibration checks have been performed on a per batch basis. Split samples have been sent to U.S. EPA Contract Laboratory Program (CLP) laboratory for analysis at a minimum frequency of 1 per 5 field samples collected. Split sample data has enforcement-quality analytical data.

A statistical data summary is presented below for the analysis of volatile compounds in the low $\mu g/l$ to the mg/l range and of chlorinated pesticides in the low $\mu g/l$ to the high mg/l range.

INTRODUCTION

A critical procedure for RI/FS activities conducted under the CERCLA program is the development of a sampling and analysis plan that is consistent with CERCLA program objectives and requirements. This plan must address the specific requirements of individual sites, be based upon the intended use of the data and be consistent with project constraints such as time and resources.

For example, in order to meet these objectives, the RI/FS project discussed in this publication was designed to be implemented in several phases. The two main intended uses of the data for the RI Phase I are (1) for health and safety and (2) for site characterization. Data collected for health and safety purposes typically are used, for example, to establish the level of protection needed for investigators or workers at a site. Standard practice is to collect baseline health and safety data, and then to collect data during site activities that involve disturbing baseline conditions, e.g., well drilling. Health and safety data generally have been collected using real-time, direct-reading portable instruments. The main disadvantage of this procedure is that it can only establish the presence or absence of volatile organic compounds and only at levels of mg/l or greater. Data collected for site characterization purposes are used to determine the nature and extent of contamination at a site. This is the process that usually requires the most data. Site characterization data are generated through sampling and analyzing waste sources and environmental media.

The site characterization should identify the specific contaminants and their concentrations, quantities and physical states. Often only a few contaminants will play a large role in determining the overall remedy for site contamination. These substances are called indicator parameters. Indicator parameters usually "represent" groups of substances; however, in this context, indicators mean a small set of substances which by reason of their large volume, high toxicity, difficulty of treatment or mobility determine the overall remedy and/or degree of contamination. It is important to identify and relate other substances to the indicator parameters when possible.

Once contaminants of concern have been identified, multiple levels of analytical support may be utilized simultaneously in response to RI/FS activity. The extent to which screening mechanisms can be used depends on their ability to identify contaminants/concentrations of concern. A most powerful form of analytical support can be developed by integrating aspects of individual analytical support levels into one collective analytical system. The type and design of this analytical system will be determined by the intended use of the data (i.e., data quality objectives). This analytical system (e.g., screening analyses coupled with U.S. EPA-approved analysis methods to produce "enforcement quality" data), coupled with a sound sampling plan design, permits a larger number of samples to be collected and analyzed. The use of less sophisticated screening techniques initially allows large numbers of samples to be screened for indicator parameters and gross contamination quickly and at low cost.

By strategically selecting which samples are to be analyzed at each analytical support level, a much higher degree of confidence can be obtained for the overall data set without sacrificing, due to project resource constraints, either the quantity of samples to be analyzed or the quality of data produced.

DESCRIPTION OF SCREENING PROGRAM

A Close Support Laboratory (CSL), supplied by the REM II team, provided field laboratory services to reduce the Contract Laboratory Program (CLP) load for the Superfund site and to facilitate decisions regarding the sequence and execution of field activities. The CSL was audited by the National Enforcement Investigation Center (NEIC), which is the enforcement litigation arm of the U.S. EPA. The CSL quality assurance (QA) program adequatedly addressed and implemented the evidenciary procedures that are required under the CERCLA program (e.g., chain-of-custody and document control). In addition, the CSL QA program and the laboratory itself were approved by the U.S. EPA for use on CERCLA projects. Fig. 1 represents a summary of the analytical QA program and the analytical decisions relating to QC sample analysis in the form of a decision-making flow chart.



Figure 1 Procedure for Evaluating QC Data from CSL Screening Analysis Program

The CSL was established near the project site and supplied preliminary screening data for soil and water samples. This procedure allowed quantification of a limited number of target compounds and determination of the presence of certain other materials. The CSL analyzed soil and water samples for indicator parameters that, although not all highly toxic themselves, are characteristic of specific waste types or toxins present at the Superfund site. These indicator parameters included trichloroethylene, total organic carbon, total organohalides, lead, arsenic and low pH values. The indicator parameters varied from one sampling site to another, and the CSL analytical procedures were modified as necessary to allow the staff to focus on specific indicators for each source area within the Superfund site.

Based on the results of initial analyses during the RI, the indicator parameters were revised as appropriate to address the requirements for the duration of the project. Selected split and duplicate samples were sent to the CLP for complete hazardous substance list (HSL) analysis in order to provide confirmation of the CSL results.

The results of the CSL analyses were used primarily to:

- Guide the selection of the aquifer interval to be screened at monitor well sites. The CSL data were used at each well site to identify the extent of contamination and the change in contaminant concentrations with depth. The screened interval was chosen to monitor the stratum of highest contaminant concentration that was consistent with the geology of the formation (e.g., presence of clay seams or buried channels).
- Assist in selecting locations for deep soil borings and Phase II wells in a timely manner. The CSL data provided a rapid indication of whether or not contaminants were present at a specific location. Placement of wells to define the maximum extent of contaminant migration was improved by the availability of such data.
- Assist the project health and safety officer to define the required level of personal protection during drilling activities at each site and to select decontamination sites and procedures for field activities.

ANALYTICAL APPROACH

CSL Organics Screening Protocol

Organic constituents were analyzed using an HNu 301 gas chromatograph with one or more of the following detector types: FID or PID. Halogenated organic compounds were selectively analyzed using a Hall-type microcoulometric detector and the HNu 301 GC. Fig. 2 represents the CSL analysis sequence for sample characterization. The CSL analytical method menu is presented as Table 1. The associated QC criteria are summarized as Table 2.



CSL Organics Screening Protocol Flow Diagram

Method performance evaluation of the screening protocols was undertaken to ascertain the efficiency of determining (volatile and extractable) screening parameters as a single peak response of the respective detectors when no column packings are used. This procedure, however, gave unacceptable resolution of the indicator compounds. Therefore, direct headspace and purge-and-trap sample injection techniques were evaluated against required

Table 1 **Close Support Laboratory Analytical Procedures**

PARAMETER	KATRIE	KETBOD	REFERENCE
Volatile Chlorinated Organics	Vater	\$010	157-846
	Soll	\$010	157-846
Volatile Nonchlorinated Organics	Vater	8015	57-846
	Soil	8015	57-846
Aromatic Volatile Organics	Vater	602	240 CFR Part 134
	Soil	602	240 CFR Part 136
Organochlorine Pasticides	Vater	608	40 CFR Part 136
	Soll	608	40 CFR Part 136
Polynuclear Aromatic Hydrocarbons	Vater	610	40 CFE Part 136
	Soil	610	40 CFE Part 134
Chlorinated Bydrocarbons	Vatar	612	40 CFR Part 136
	Soil	612	40 CFR Part 136
Total Phenols	Vater Soil	5108 5108	3 Standard Hethods Standard Hethods
Volatile Organics	Yater	Screen	CSL (in-house)
	Soil	Screen	CSL (in-house)
Extractable Organics	Vater	Screen	CSL (in-house)
	Soil	Screen	CSL (in-house)
Vater	9040 Soil	5V-846 9040	57-846
Lead	Vater	3168	Standard Hethods
	Soil	3168	Standard Hethods
Arsebic	Vater	307C	Standard Rethods
	Soll	307C	Standard Nethods
Sulfate	Vater	426C	Standard Nethods
	Soil	426C	Standard Rethods

1 Test Methods for Evaluating Solid Waste, SW-846 2nd Ed., U.S. EPA (1982)

2 Federal Register, Vol. 49. Dv. 209, 40 CFR Part 136 Appendix A, U.S. EPA (10/26/84)

3 Standard Methods for the Examination of Water and Wastewater, 15th Ed., APHA-AWWA-WPCF (1980)

		Table 2		
Close	Support	Laboratory	Quality	Control
	Criteria i	or Target C	ompour	ds

CKS Number	Parameter/ Compound	Natri a	Detection Linit	Digilizate Precision (NPD)	Retric Spiler Secondry (31)	D'A Chack Sample (SP.)	(h. Sampla Propanicy
30-29-3	4,4°-000	Vatar Setil	0.012 mp/L 1-1 -1/1	10 15	18-127 23-134	50-120 8/4	(1/10) (1/10)
60- 57-1	Disidria	Vecar Setil	0.008 ug/L 0-2 ug/lg	20 25	53-136 31-136	40-130 IVA	(1/10) (1/10)
78-10-4	Trichioros chere	Vistor Soil	0.13 պր/ե 12 պր/եց	20 25	תו הי קו ני	75-115 #44	(1/10) (1/10)
101-15-2	Parol(s)	Veter Soli	1.0 up/L Li up/Rg	10 15	73-125 73-125	85-115 874	(1/10) (1/10)
14255-01-0		Vistar Seij	100 ug/L 100 ug/Kg	30 35	75-125 75-125	85-115 N/A	(1/10) (1/10)
7440-38-2	Arrente	Vistair Soil	1 че	10 15	75-125	85-115* 844	(1/10) (1/10)
R/1	Volatiles (ecrem)	Via Lar Taxi	10 up/L 1 up/Te	10- 10-	10-130- 60-140-	73-1234 75-1234	(1/30) (1/30)
R/4	Entractablas (acrean)	Vintear Sint 1	10 ug/L 1 mg/%g	22- 12-	10-110- 40-140-	73-120-	(1/10) (1/10)

Represents an advisory limit only

method performance criteria (especially achievable detection limits) using packed analytical columns. Further sample characterization was performed as dictated by sample-specific project requirements. Additional organic parameters included: halogenated volatiles, non-halogenated volatiles, halogenated semi-volatiles (extractables), non-halogenated semi-volatiles and chlorinated pesticides. Methods used were standard U.S. EPA reference methods or in-house modified methods that had been shown to produce comparable data that had the required defined performance specifications. Initial screening methods were developed using reference standards and U.S. EPA QA check samples spiked into reagent water.

Screening Procedures for Organics Limitations

The procedures for sample extraction and preparation were developed to provide rapid "screening" of field samples in order to determine the presence or absence of organic contaminants. The procedures were designed to meet project goals with respects to analysis "turnaround time" and analytical results (i.e., specificity and sensitivity to the indicator parameters). Confirmation of compound identity and exact quantitation of sample components were not required (such analyses could be performed on a "sample by sample" basis, if desired). Analytical results thus represented estimated quantities of "tentatively identified compounds" or of classes of constituents (e.g., non-halogenated organics) present in the sample. Spikes, recoveries and method sensitivity may vary due to composition of the sample matrix and to the presence of interferents that may affect the performance of the gas chromatographic column.

Interferences

Analytical interferences are minimized due to the selectivity of the electrolytic conductivity detector. Method interferences may be caused by contaminants in solvents, reagents, glassware and the chromatographic system. The analysis of laboratory method blanks with each batch of samples provided a mechanism for the routine monitoring of all interferences that would affect analytical performance.

Contaminants were identified by comparing the retention times of sample peaks to the retention time of standards. This technique is not definitive, and identifications were considered tentative. Two to three column identifications could have been made for more definite identification, but this procedure requires considerably more time. Analytical conditions did not always maximize resolution, which is the ability to separate compounds. Method development/optimization was conducted as priorities dictated. Since compound identifications were tentative, exact resolution was not always critical. The desired analytical resolution was determined by the objectives of the sampling.

Relative measurements of contaminant peaks were accomplished by comparing the peak heights of contaminants to the peak heights of the standards and utilizing the following formula:

Peak height
$$\frac{SAM}{STD} \times \text{attenuation} \frac{SAM}{STD} \times$$

Injection $\frac{STD}{SAM} \times \text{concentration STD}$ (1)

where:

SAM = sample STD = standard

Since concentration measurements by these methods were based on peak height rather than peak area (integration), the values generated are approximate. Numbers were reported in ranges where appropriate to avoid misinterpretation of the data. The limitations, tentative identifications and approximate concentrations were noted on all analytical reports and in all presentations of the data.

EXPERIMENTAL SUMMARIES: SOIL AND WATER QUALITY

Split samples from all soil and groundwater sampling efforts were submitted to the CSL. The CSL performed screening analyses on the various samples to provide rapid (usually less than 2-hour turnaround time) assessment of the presence or absence of organic contamination.

The original work plan called for the CSL to perform screening analysis for volatile and extractable organic compounds and
specific analyses for three inorganics (arsenic, sulfate and lead) and one organic (phenol). The additional time required for the specific inorganic and organic analyses, however, created an unacceptable delay (in terms of time and cost) in field activities, specifically in selecting the depth interval to be screened and completing the well. Consequently, these specific analyses were not performed. The CSL did perform analyses for volatile and extractable organics as described in the sections below.

EXTRACTABLE ORGANICS ANALYSIS

Soil

Approximately 10 g (recorded to the nearest 0.1 g) of wellmixed, undried soil were weighed into a 100 ml serum bottle. Ten ml of 50% acetone/50% hexane were then added (complete immersion of the soil was required). The bottle was capped and then sonicated for 10 min. Subsequently, the extract was allowed to settle and then was decanted into a 16 ml glass vial (Teflon-lined cap) containing approximately 1 g of sodium sulfate. The resulting extracts were stored at less than 4 °C until gas chromatographic analysis.

Water

Approximately 10 g of water (recorded to the nearest 0.1 g) were weighed into a 16 ml vial having a Teflon-lined cap. Two ml of hexane were added, and the vial was capped and shaken for 1 min. The phases were allowed to separate for 10 min. The hexane phase then was transferred with a clean Pasteur pipet to a 5 ml septum-sealed vial containing approximately 0.5 g of sodium sulfate. The extracts were stored at less than 4 °C until required for gas chromatographic analysis.

 Table 3

 Extractables Duplicate Sample Pair "Peak Response Precision"

Duplicate Pair I.D.	Hatrix	Peak Response ²	RPD of Response	Reported Estimated Concentrations Range for Selected Peak
l. 1. Duplicate	Soil	No Response Detected No Response Detected	-	No peaks detected, MOL = 0.5 ppm
2. 2. Duplicate	Soil	200 500	86	Low ppn range
3. 3. Duplicate	Soil	500 400	22	Low ppa range
5. 5. Duplicate	Soil	No Response Detected No Response Detected	-	No peaks detected, MOL = 0.5 ppa
6. 6. Duplicate	Water	12,000 15,000	22	Low ppa range ³
7. 7. Duplicate	Water	No Response Detected No Response Detected	-	No peaks detected, MOL = 10 ppb
8. 8. Duplicate	Water	No Response Datacted No Response Datacted	-	No peaks detected, MOL = 10 ppb
9. 9. Duplicate	Water	No Response Detected No Response Detected		No peaks detected, MOL = 10 ppb
10. 10. Duplicate	<u>Vater</u>	No Response Detected No Response Detected	-	No peaks detected, MOL = 10 ppb

i Target value for RDP = 50

² Peak response listed for sample peak having retention time closest to dieldrin peak. (Peak response = peak height \times attentuation factor.)

³ Peak reported is outside the retention time range of organochlorine pesticides.

Quality Control

Spiked samples and duplicates were analyzed at a minimum frequency of one per 10 samples extracted and a minimum of one per batch of samples. The matrix spikes were prepared by spiking approximately 10 g of sample (recorded to the nearest 0.1 g) with amounts of standards to give levels of 5 mg/l p,p'-DDT and 2 mg/l dieldrin. A method blank was prepared for each sample extraction batch.

Initial and final calibrations were performed daily using a standard mixture of 5 ng/ μ l p,p'-DDT and 2 ng/ μ l dieldrin. Instrument conditions were adjusted to achieve a minimum response of one-half full-scale detection. Chromatographic temperatures, instrument attenuation, retention times and responses (peak height) of analytical standards were recorded daily. A QC check sample was analyzed routinely to calibrate retention time range for the organochlorine pesticide class. A weekly three-point calibration was performed to ensure linearity across the attenuation range (i.e., at all attenuation settings) of the chromatographic detector. The duplicate sample analysis results are summarized as Table 3. The spiked sample analysis results are summarized as Table 4.

 Table 4

 Extractables Spiked Sample Recovery: Acceptability Criteria¹

	Spike Amount		Percent Recovery		
Hatrix	DDT	Dieldrin	DOT	Dieldrin	Reported Concentration Ranges of Sample Components
Vater	50 ppb	20 ppb	93	94	No peaks detected, MQL = 10 ppb
Vater	50 ppb	20 pgab	45	71	No peaks detected, HQL = 10 ppb
Vater	50 ppb	20 ppb	63	78	No peaks detected, HQL = 10 ppb
Water	5	2	57	57	No peaks detected, MQL = 10 ppb
Vater	50	20	100	92	No peaks detected, MQL = 10 ppb
Soil	5 ppm	2 ppm	93	70	No peaks detected, HQL = 0.5 ppm
Soil	2 ppm	1 ppm	75	61	7 peaks detected in the high ppb to low ppa range ²
Soil	5 ppm	2 ppm	58	59	8 peaks detected in the high ppb to low ppe range ²
Soil	5 ppm	2 ppm	103	129	No peaks detected, HQL = 0.5 pps
Soil	5 ppm	2 ppm	90	93	No peaks detected, HQL = 0.5 ppm
	Matrix Water Water Water Water Soil Soil Soil Soil Soil	Spike Water 50 ppb Water 50 ppb Water 50 ppb Water 50 ppb Water 5 Water 50 Soil 5 ppa Soil 2 ppa Soil 5 ppa	Spike AnountMatrixDDTDieldrinWater50 ppb20 ppbWater50 ppb20 ppbWater50 ppb20 ppbWater52Water52Water5020Soil5 ppa2 ppaSoil2 ppa1 ppaSoil5 ppa2 ppaSoil5 ppa2 ppaSoil5 ppa2 ppaSoil5 ppa2 ppaSoil5 ppa2 ppaSoil5 ppa2 ppa	Spike Anount Percent Matrix DOT Dieldrin DOT Water 50 ppb 20 ppb 93 Water 50 ppb 20 ppb 45 Water 50 ppb 20 ppb 63 Water 5 2 57 Water 50 20 100 Soil 5 ppn 2 ppn 93 Soil 2 ppn 1 ppn 75 Soil 5 ppn 2 ppn 58 Soil 5 ppn 2 ppn 58 Soil 5 ppn 2 ppn 90	Spike Anount Percent Recovery Matrix DOT Dieldrin DOT Dieldrin Water 50 ppb 20 ppb 93 94 Water 50 ppb 20 ppb 45 71 Water 50 ppb 20 ppb 63 78 Water 50 20 ppb 63 78 Water 50 20 ppb 63 78 Water 50 20 ppb 63 78 Water 50 20 ppb 63 78 Water 50 20 100 92 501 5 ppa 2 ppa 93 70 Soil 2 ppa 1 ppa 75 61 50 59 501 5 ppa 2 ppa 58 59 Soil 5 ppa 2 ppa 103 129 501 5 ppa 2 ppa 90 93

1 The target criteria for recoveries were:

	DDT	Dieldrin
Soil	23-134	31-134
Water	38-127	52-126

2 The retention times of the peaks were within the retention time range of organochlorine pesticides.

GAS CHROMATOGRAPHY

The following instrumental and chromatographic conditions were used:

- Analytical Column: 180 cm × 0.6 cm glass, 2 mm ID
- Column Packing: 3% ov -1 on 100/120 Supelcoport
- Column Temperature: 100 °C Initial, 1 min. hold 30 °C/min ramp to 270 °C final
- Detector/injector temperature = 290 °C
- Carrier Gas Helium (40 ml min.)

Chromatography

A 0.5 to $3.0 \,\mu$ l aliquot of the sample extract was injected into the gas chromatograph using the solvent-flush injection technique. Sample I.D., attenuation setting and injection volume were recorded. The extracts were screened at the attenuation settings at which the standard calibration was performed. Attenuation was adjusted to keep sample response peaks on-scale. Levels of peaks detected were estimated by the comparison of the peak heights of the sample to the peak heights of standard p,p'-DDT and dieldrin. Samples for which the detector response was out of the attenuation range of the chromatographic detector were diluted with hexane and reinjected.

VOLATILE ORGANICS ANALYSIS

Approximately 10 g of well mixed sample (soil or water), recorded to the nearest 0.1 g, were weighed into a tared 100 ml serum bottle. The bottle was crimp-sealed with an aluminum seal containing a Teflon-lined rubber septum. The bottle was allowed to equilibrate 1 hour in a 90 °C water bath before chromatograph analysis.

Quality Control

Spiked samples and duplicate samples were analyzed at a frequency of one per 10 samples analyzed and a minimum of one per batch of samples. The samples were spiked with a U.S. EPA QC check sample using an amount which gives levels of 60 μ g/l trichloroethylene and 30 μ g/l tetrachloroethylene. A reagent and glassware blank was prepared and analyzed with each sample batch.

Initial and final GC calibrations were performed daily using an aliquot of deionized water spiked at levels of 50 μ g/l trichloroethylene and 250 μ g/l toluene. Chromatographic temperatures, instrument attenuations, analytical standards retention times and responses were recorded daily. A multilevel calibration (range = 50 μ g/l to 5 mg/l TCE, 100 μ g/l to 5 mg/l toluene) was performed on a weekly basis using toluene for FID calibration and a toluene

Table 5

Volatile Duplicate Sample Pair "Peak Response Precision""

ħ	Jr I.D.	Hatrix	Paak ² Naaponse	RFD of Nexponse	Reported Estimated Concentration ³ Renge forSelected Peek
1.		Soil	No Response Detected	_	C50 ppb
1.	Duplicate	Soil	No Nasponse Detected		
z .		Soil	40	66.6	Low poth range
2.	Duplicate	Soil	80		
3.		Soil	320	11.8	Low ppb rungs
3.	Duplicate	Soil	360		
4.		Soil	800	18.2	Hadium ppb range
4.	Duplicate	Soil	960		-
5.		Water	60	0	Low ppb range
5.	Duplicate	Water	60		
6.		Water	No Response Detected	-	(50 ppb
6.	Duplicate	Via Lar	No Response Detected		
7.		Soil	1,040	7.4	Hedium ppb range
7.	Duplicate	Soi)	1,120		
8.		Water	3,200	0	High ppb range
8.	Duplicate	Vister	3,200		
9.		Water	360	10.5	Low gob mange
9.	Duplicate	Vister	400		
10.		Vater	640	22.2	Hadium ppb range
10.	Duplicate	Water	800		

1 The target value for duplicate precision RPD = 50%.

2 Peak response listed for sample peak having retention time closest to TCI- peak. (Peak response - peak height × attentuation factor.)

3 Reported ranges for volatile analysis (based on TCE response)

and trichloroethylene mixture for PID calibration. The calibration standards were prepared in DI organic-free water.

These extended range calibration curves were used to estimate amounts of sample component responses which fell out of the daily standard attenuation setting (i.e., amounts greater than that in the normal working range). The daily matrix spike was compared to the multilevel calibrations to assure acceptable correlation between sample matrix spikes and deionized water calibration spikes. The volatile analysis PID calibration was performed at five calibration points ranging from 50 $\mu g/1$ TCE to 5 mg/1 TCE. The mean RF and percent RSD were calculated for the multilevel calibrations. The target value for percent RSD was for $\leq 25\%$. The daily matrix spike was at a level of 60 $\mu g/1$ TCE.

The duplicate sample analysis results are summarized in Table 5, and the spiked sample analysis results are summarized in Table 6.

Table 6 Volatiles Spiked Sample Recovery: Response Factor Acceptability Criteria

Spikad Sample I.D.	Hatrix	Spike Anount	Numperson Pactor, of TUE	20 of Sample Matrix Spike N7 Vs. Calibration Standard N7	Reported Concentration Ranges of Seeple Cosporents
1	Natar	60 ppb	3.3	'n	No peaks detected, HQL = 50 ppb
2	Water	60 ppb	4.0	9	1 pank in the low ppb range
3	Water	60 ppb	5.0	3.8	1 pank in the matium \longrightarrow high ppb compa
4	Soil	60 ppb	5.3	1.9	No paaks detected, HQL = 30 ppb
5	Vator	60 ppb	4.0	C	I peak in the low ppb range
6	Vator	60 ppb	4.0	9.1	1 peak in the low ppb range
7	Scil	60 ppb	4.0	9.1	2 peaks in the low ppb range
	Seil	60 ppb	4.0	20.8	3 pasks in the low ppb range
,	Soil	60 ppb	4.0	20.8	1 peak in the low ppb range
10	Soil	60 ppb	4.0	11.1	1 pask in the madium ppb range

1 The target criteria for %D was 25%

2 Response factor # TCE response/amount (ppb)

3 %D = (RF daily calibration standard) — (RF sample spike)/RF daily calibration standard (daily calibration standard = 50 ppb TCE in D1H₂O)

Gas Chromatography

The following instrumental and chromatographic conditions were used:

- Analytical Column: 180 cm × 0.3 cm Stainless Steel
- Column Packing: 5% AT-1200/1.75% Bentone-34 on 100/120 Chromosorb WAW
- Column Temperature: 63 °C initial, 2 min hold time 6 °C/min to 93 °C final
- Detector/Injector Temperature: 150 °C
- Carrier Gas: Helium 40 ml/min

Chromatography

A 4 ml portion of the sample headspace was injected into the gas chromatograph. Sample 1.D., injection volume and instrument attenuation were recorded. Initial attenuation was set at the same level (setting) that had been used for the calibration standard analysis and was subsequently adjusted to keep sample response peaks on-scale. Concentration levels of peaks detected were estimated by comparing sample peak heights to the standard calibration curve peak heights.

RESULTS AND DISCUSSION

CSF Quality Assurance (QA) Program

The CSL QA program for screening analysis included the following key QC procedures: (1) Establishment of linear working range using a five-point calibration curve, (2) weekly three-point calibration range linearity verification using U.S. EPA reference standards, (3) daily continuing calibration check, (4) duplicate sample analysis at a minimum frequency of 10% per matrix, (5) spiked sample analysis at a minimum frequency of 10% per matrix, (6) reagent blank analysis at a minimum frequency of 10% per matrix, and (7) the limit of quantitation (LOQ) was determined daily by calculating the peak response for a matrix spike of reagent water or background soil.

Due to the nature of screening analysis protocols and the method for reporting results, the QC criteria for the above procedures were considered to establish advisory limits only. Data were not "rejected" on the basis of exceeding the QC limits, although samples may have been reanalyzed if the criteria were grossly exceeded.

Analytical Results

Selected representative analytical results are presented in Tables 7 and 8 as comparative examples of the sample analysis data as reported by the CSL and by the CLP laboratory. In order to assess the equivalency of these two data sets, the following factors must be considered: (1) relative detection limits, (2) analytical selectivity, (3) method of reporting and (4) intended use of each data set.

In order to use CLP data for project purposes, the data first must be "validated" according to specified U.S. EPA protocols by trained data validation specialists. The data validation task for the Phase I samples of this project was estimated to require 1300

Table 7 Comparison of CSF Volatile Results Versus Contract Laboratory (CLP) Results'

Sample I.D.	Sample Matrix	CSP Reported Data	CLP Reported Data
1	Soil	1 peak in the high ppb to low ppm range 25 peaks in the medium ppm to high ppm range	Ethyl Benzene = 11,000 ug/Kg Total Xylenes = 41,000 ug/Kg Chloroform = 820 ug/Kg Hethylene Chloride = 5,800 ug/Kg Ten Tentatively identified compounds ranging from 790 to 2,400 ug/Kg
2	Soil	No peaks detected, MQL = 50 ppb	Chloroform ³ = 8 ug/Kg
3	Soil	l peak in the high ppb to low ppm range	1 tentatively identified compound at 5 ug/Kg
4	Water ⁶	5 peaks in the ₅ high ppb to low ppm range ⁵	<pre>1,1,1-Trichloroethane = 740 ug/Kg Ethyl Benzene = 890 ug/Kg Total Xylenes = 4,700 ug/Kg 1 tentatively identified compound at 600 ug/Kg</pre>

1 Validated results were available for only a few of the samples analyzed by the Contract Laboratory, thus a full database comparison of CSF vs. CLP results cannot be performed at this time.

- 2 The remaining HSL volatiles were reported as less than the sample detection limits. The sample detection limits were reported between 1,600 and 3,300 µg/kg due to the required dilution to bring the reported compounds within the CLP calibration ranges.
- 3 Chloroform is not detected by the PID detector and has a low response to the FID detector due to the high degree of chlorination.
- 4 Based on the retention time and a negative PID response, this result is indicative of methanol present in the sample. Methanol was used by field sampling personnel during decontamination procedures. Based on this result, the field sampling personnel were advised to allow longer periods of drying time for the surface soil sampling equipment before proceeding with the next sampling site.
- ⁵ The CSF chromatographic fingerprint was observed to be indicative of ethyl benzene and xylene isomers. The deionized water obtained for drilling rig decontamination procedures was found to be contaminated, prior to use, by the CSF results. This data prevented contamination of the drill site locations and the samples collected by the use of this deionized water for drilling rig decontamination procedures.

6 Decontamination procedure rinsate.

hours and has not been completed in time to reference the entire Phase I data base in this publication, whereas the CSL staff was able to provide useful data to the project management and field crews in a time frame of several hours. Two examples of useful information obtained during CSL screening follow.

On the basis of the analysis of decontamination rinsate samples, the CSL discovered after the first day of monitor well drilling that the decontamination rinse water source had been contaminated with several organic compounds by a storage tank that had not been adequately cleaned to remove organics. The CLP corroborated this finding with enforcement-quality data.

 Table 8

 Comparison of CSF vs. CLP Extractable Data Results'

Sample I.D.	Matrix	CSF Reported Data ²	CLP Organochlorine Pesticides Reported Data
1	Soil	No peaks detected, HQL = 0.5 ppm	No pesticides reported Sample Detection Limits 10 to 200 ug/Kg
2	Soil	9 peaks in the high ppb to low ppm range The peaks were within the retention time range for Organochlorine Pesticides	Heptachlor = 150 ug/Kg 4,4'-DDE = 830 ug/Kg Endrin = 210 ug/Kg 4,4'-DDD = 540 ug/Kg 4,4'-DDT = 5,700 ug/Kg Endrin Ketone = 480 ug/Kg Chlordane = 1,198 ug/Kg
3	Soil	No peaks detected, MQL = 0.5 ppm	No pesticides reported Sample Detection Limits 82 to 1,600 ug/Kg
4	Soil	8 peaks in the high ppb to low ppm range The peaks were within the retention time range for organochlorine pesticides	Heptachlor = 1,100 ug/Kg Dieldrin = 960 ug/Kg 4,4'-DDE = 3,100 ug/Kg 4,4'-DDE = 1,900 ug/Kg 4,4'-DDT = 17,000 ug/Kg Endrin Ketone = 1,400 ug/Kg Chlordane = 4,670 ug/Kg

1 Validated results were available for only a few of the samples analyzed by the contract laboratory, thus a complete database comparison of CLP vs CSF results cannot be performed at this time.

2 CSF reported concentration ranges for extractables High ppb = 500 ppb to 1 ppm

Low ppm = 1 to 10 ppm

3 Chlordane exhibits a multipeak response

Similarly, the CSL reported that the decontamination procedure for the surface soil collection equipment was inadequate to remove all residual methanol from a decontamination solvent rinse step. The CSL reported a positive methanol value for the decontamination rinsate sample. The CLP laboratory did not report finding methanol per se or as a tentatively identified compound. The analytical protocols for CLP routine analytical services, however, do not allow for the detection of methanol. Consequently, this problem would not have been discovered if the CSL had not been utilized or if the CSL staff had not been aware of the specific project procedures.

CONCLUSIONS

The Close Support Laboratory and analytical screening protocols concepts as implemented for this project allowed for the production of reliable analytical data on a short turnaround basis. The analytical services provided were relatively low-cost compared to commercial or CLP laboratories and addressed projectspecific requirements.

Due to the nature of the screening program (i.e., relative lowcost compared to standard GC protocols) and quick turnaround (approximately 2 hours/sample), the following benefits to the project were realized: Selected priority and enforcement-sensitive samples could be sent to the CLP laboratory for confirmation of screening results; the accuracy of the site characterization and contaminant plume(s) mapping was significantly improved as a result of the increased number of samples that could be analyzed with a fixed project budget; the responsiveness of the analytical staff to changing project requirements and schedules was increased as a result of the large degree of communication with the field personnel.

This procedure enabled the field staff to better understand site

conditions and to select subsequent well locations, soil borings and screened intervals in wells on the basis of reliable data rather than previously assumed conditions or estimates.

As can be seen from a review of the data in Tables 3 to 8, the CSF screening methods provided accurate reproducible analyses within the limits of the screening program.

The U.S. EPA's Expedited Response Action Program

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ABSTRACT

Revisions of the National Contingency Plan redefine the response categories of "removal actions" and "remedial actions" so that removals now include all activities formerly considered immediate removals, planned removals and Initial Remedial Measures (IRMs). These changes in response categories will expedite many cleanup activities.

A program is being implemented by the Hazardous Site Control Division of the U.S. EPA to facilitate response actions at NPL sites. These actions are referred to as Expedited Response Actions (ERAs). Removal actions taken under this program will be performed by remedial contractors to ensure continuity with remedial investigation/feasibility study (RI/FS) activities and schedules as well as consistency with final remedial alternatives. The approach will entail the use of an Engineering Evaluation/ Cost Analysis procedure, plans and specifications development, competitive bidding and construction management to plan, design and implement the project.

The main benefit of the ERA process is that it results in the cleanup of site contamination without the implementation of a full RI/FS. As a result, obvious technical site cleanup alternatives can be selected, designed and implemented on a fast-track basis.

The authors describe the concept of the ERA Program and how it will improve the U.S. EPA's ability to rapidly clean up NPL sites. The procedures that are in use to implement the program are explained, and an example of an ERA that has been conducted is discussed.

INTRODUCTION

An expedited response action (ERA) is a removal action implemented at an NPL site by a remedial response contractor. The action must be conducted within the time and cost constraints of removal actions. The statutory limits of \$1 million and 6 months currently apply; these are expected to be revised upward when CERCLA is reauthorized. These actions may include initial measures at a site slated for a comprehensive remedial action later (these used to be called IRMs, initial remedial measures), a rapid cleanup required based on data collected during an ongoing remedial response, or a permanent remedy for a site with limited cleanup requirements.

As defined by Section 101(23) of CERCLA and cited in Section 300.6 of the NCP, "remove or removal means the cleanup of released hazardous substances from the environment; such actions as may be necessary to monitor, assess and evaluate the release or threat of release of hazardous substances, the disposal of material or the taking of such other actions as may be necessary to prevent, minimize, or mitigate damage to the public health or welfare or the environment...." Based on this definition, a removal action may include capping, on-site treatment or other measures in addition to or in place of actual removal of hazardous materials. The term "remedial action," then, refers to work conducted under the U.S. EPA's CERCLA remedial response program, which includes long-term cleanups with the objective of a permanent remedy for the site. An ERA is an action under the CERCLA removal authority, conducted by a remedial contractor at an NPL site. Removal actions that must be accomplished quietly and actions at sites that are not on the NPL will be conducted by removal contractors.

The purpose of the ERA is to accomplish rapid cleanups by streamlining the remedial investigation/feasibility study process for operable units or sites where the most effective mitigation method is readily evident. The level of detail required in the analysis of alternatives for these actions depends on the urgency of the required response.

General guidelines for determining the suitability of a site for an ERA include the following:

- The circumstances meet removal action criteria
- The ERA remedy is consistent with the final permanent remedy
- The remedy can be accomplished within the statutory cost and time constraints specified for removal actions

PURPOSE

The primary purpose of conducting an ERA is to expedite cleanup at NPL sites where solutions are clear and where an emergency situation does not exist but a release or threat of release exists. ERAs may include removal actions that need not be done immediately; in this case they will use a response schedule that will allow for completion of an engineering evaluation/cost analysis and competitive procurement of a construction subcontractor. Besides expediting the cleanup of hazardous waste situations, the ERA also:

- Accomplishes partial site cleanup consistent with remedial response actions
- Makes future RI activities easier to accomplish by removing or controlling on-site wastes
- Improves the public perception of the Superfund program by rapidly accomplishing partial site cleanups or by furnishing alternative water supplies

The analysis of alternatives in an ERA is documented in an engineering evaluation/cost analysis report. This document serves as the basis for the action memorandum (EPA's decision document for removal actions), much as the RI/FS report serves as the basis for the Record of Decision for remedial projects.

COORDINATION OF REMOVAL AND REMEDIAL PROGRAMS

The selection of a remedial or removal contract vehicle for the conduct of a removal action involves multiple factors. The selection is based on the time critical nature of the response, the status of on-going site activities, long-term plans for the site, experience and capability of the remedial project manager or on-scene coordinator, technical expertise required and contract capacity and accessibility. Guidelines for determining the lead program for removal actions are diagrammed in Fig. 1.

All removal actions, regardless of program lead, must be consistent with CERCLA and the NCP. Response activities under the removal authority are characterized by an urgency of response that affects the extent to which they must address certain areas specified in the NCP. As specified in Section 300.65 of the NCP, "removal actions shall, to the greatest extent practicable, considering the exigencies of the circumstances, attain or exceed applicable or relevant and appropriate federal public health and environmental requirements."

THE ERA PROCESS

ERA and the RI/FS Process

The ERA normally will proceed concurrently with an RI/FS assignment. However, these two activities share only front end data collection tasks. The goal of the ERA process is to break out feasible ERA units from an RI/FS assignment and fast-track the evaluation of alternatives for these discrete contamination situations. In this way, the ERA evaluation can proceed rapidly to the point where a decision about the potential for design and implementation of an ERA can be made. If ERA criteria are satisfied, then the ERA process results in a rapid cleanup of part or all of a hazardous waste situation. If the ERA criteria cannot be satisfied, then either a full or limited RI/FS can proceed with little or no interruption. A diagram showing the relationship of the ERA process to a typical RI/FS assignment is presented in Fig. 2

ERA Components

An ERA is conducted in four phases in which feasible removal actions are screened, evaluated, selected and implemented. ERA activities include the following:

- Phase I-Preliminary Screening of ERA Alternatives
- Phase II-Engineering Evaluation and Cost Analysis (EE/CA)
- Phase III-Design and Contractor Procurement
- Phase IV—ERA Implementation

In Phase I of an ERA study, data gathering activities commence (Fig. 3). At this stage in the ERA evaluation, data needs particular to the complete ERA evaluation will be identified. Preliminary ERA candidate option screening will address issues such as:

- · Potential for quick cleanup
- Identification of ERA alternatives that would be consistent with remedial response actions
- Likelihood of remedies being completed on a fast-track time schedule with a limited amount of engineering or expensive data gathering
- Compliance with initial ERA inclusion criteria

If a site meets the initial ERA screening criteria, then a Phase II ERA evaluation will be conducted. In Phase II, data gaps are filled, and an engineering evaluation and cost analysis (EE/CA) is completed (Fig. 4). The results of the EE/CA are compiled in an EE/CA report. After review by the U.S. EPA, the report is issued for public comment. During the public comment period,



Figure 1 Decision Tree for Removal and ERA Projects



Figure 2 Relationship of ERA Process to RI/FS Assignment Flow



Figure 3 ERA Phase I—Preliminary Screening



Figure 4 ERA Phase II—Engineering Evaluation/Cost Analysis

the contractor may proceed with initial preparation for design of the removal action.

When an ERA alternative is selected for implementation, Phase Ill is conducted (Fig. 5). In this phase, the contractor prepares Invitation for Bid (IFB) or Request for Proposal (RFP) contract documents, advertises and conducts the bid or proposal evaluation. Selecting the cleanup firm is EPA's prime contractor's responsibility.

During Phase IV, the cleanup contractor is notified to initiate the execution of the remedial work (Fig. 5). Upon completion of the work, an ERA Completion Report is prepared which summarizes the technical and financial aspects of the ERA and compares these actual results to the initial estimates.

ENGINEERING EVALUATION/COST ANALYSIS

An engineering evaluation/cost analysis (EE/CA) will be conducted for removal actions where time permits. The EE/CA is ^{conducted} in Phase II of the ERA process, beginning with a limited number of alternatives that have been selected through screening in Phase I. Phase II entails refinement and specification of the alternatives, followed by a detailed analysis based on



Figure 5 ERA Phases III and IV—Design, Procurement and Implementation

the following criteria:

- Public health, welfare and environmental impacts
- Technical feasibility
- Institutional considerations
- Cost

The evaluation addresses areas that also are considered in the overall RI/FS for the site. Potential impacts upon public health, welfare or the environment are evaluated for each alternative with the purpose of eliminating alternatives that may have significant adverse impacts or may not adequately protect the environment. Under technical considerations, each remedial alternative is evaluated for performance, reliability, implementability and safety. Institutional concerns include the areas of community relations, PRP involvement, permit requirements and compliance with relevant and applicable regulatory requirements. Evaluation of costs should consider estimation of costs, present worth analysis, sensitivity analysis and summarization of alternatives analysis. The level of detail of the analysis will be commensurate with the complexity of the proposed project.

The results of the detailed evaluation of response alternatives will be compiled in the EE/CA report. The EE/CA report provides the U.S. EPA decision-makers with the information needed to select an alternative for implementation. The EE/CA report will form the basis for the ERA Action Memorandum, the U.S. EPA's decision document for the expedited response action.

Evaluate Data Requirements

Data collected during the initial site visit, the extent of contamination survey and any additional specific limited site visits provide the data base for the screening and detailed analysis of alternatives.

If the initial site visit is conducted with adequate consideration for the alternatives defined in Phase I, the data base should be adequate to complete the EE/CA. Any followup data collection activities should focus on the needs for properly assessing alternatives. Some examples of follow-up activities include:

- Verification sampling and analysis
- Analysis to clearly define extent of contamination
- Determination of actual or potential exposure to hazardous substances, pollutants or contaminants by nearby populations, animals or food chain and assessment of health impact of such exposure
- Characterization of waste material for detailed determination of process applicability
- Pilot testing of various solidification/fixation agents with waste material
- Detailed analysis of embankment or dike stability for support of heavy equipment

Development and Analysis of Alternatives

Each candidate alternative must be developed in sufficient detail for comparative analysis. Utilizing the base map and other data obtained through the initial site visit and other data collection activities, site-specific descriptions of each alternative are developed. The chronology and implementation schedule for each alternative also is considered under the technical evaluation. The descriptions of the alternatives should include the following:

- Plan of operations
- Ancillary support requirements
- Contingency requirements
- Equipment needs
- Operations and maintenance
- Sidestream waste generation and management
- Off-site disposal requirements
- Easements

Engineering and Technical Feasibility

The technical feasibility of each alternative should be summarized in terms of expected performance, reliability, implementability and safety. Technical evaluation of the alternatives also must consider the applicability of alternative technologies to the site, whether or not the alternative results in a permanent remedy, and if the alternative is consistent with the final remedy for the site.

The implementation schedule also is taken into consideration as part of the technical evaluation.

Cost Analysis

The objective of this activity is to develop cost estimates for each alternative. Cost accuracy should be within a targeted range of +50% to -30%. Costs should include implementation, design and construction contingencies, construction management, operations and maintenance and closure/post closure, as applicable.

Summary of the Alternatives Evaluation

The results of the detailed assessment of the alternative ERAs should be assembled and analyzed on a comparative basis. For each alternative, the summary should present the following in tabular form:

- Public health and environmental concerns
- Estimated construction cost
- Technical concerns
- Construction concerns
- Compatibility with final remedy

This analysis should include the reasons for differences among alternatives. For example, if costs are significantly different, the basis for this difference should be presented. It also should be noted if the alternatives result in permanent remediation or if they require followup remedial or removal activities.

CASE STUDY

One of the first ERAs conducted was for the Gregory Incline and Tailings site, part of the Clear Creek/Central City NPL site in Colorado. The Clear Creek site consists of five sources of acid mine drainage and unstable tailings that resulted from hard rock mining and milling. The sites are located in one of the most concentrated areas of hard rock mining in Colorado; there are over 800 abandoned mine workings and adits located in this mining district around the Central City/Black Hawk area.

A potential environmental threat was identified at the Gregory Incline and Tailings site during field investigations as part of an on-going RI/FS. A timber crib retaining wall, built between 1880 and 1889, supports mine tailings contaminated with heavy metal. This wall has failed in part and has deteriorated to the point that mass failure of the wall is imminent. The general site layout of the Gregory Incline and Tailings site is shown on Fig. 6.

Alternative Analysis

The preliminary screening analysis evaluated the feasibility of five various remedies to correct the unstable tailings at the Gregory Incline and Tailings site. These alternatives included the following:

- No action
- Stabilize the tailings slope
- Replace the retaining wall
- Remove the tailings
- Isolate the creek from the tailings

Preliminary screening of these alternatives revealed that the removal of the tailings alternative exceeded ERA cost constraints, and an extension could not be justified. In addition, the no action alternative was unresponsive to CERCLA goals. The remaining three alternatives were evaluated in more detail. As part of the detailed analysis, three variations of the wall replacement alternative were identified: reinforced earth, rigid retaining wall and flexible retaining walls.



Figure 6 Gregory Incline and Tailings Site Layout

Compatibility with Final Remedy

The alternatives proposed to stabilize the tailings were determined to be compatible with the permanent remedy for the Clear Creek site, which includes isolation of the tailings and control of seepage water quality. Based on preliminary analysis conducted in the on-going RI/FS for the Clear Creek site, the most cost-effective solution to controlling the spread of toxic tailings will be to leave the tailings at their present location, isolate them from direct human or animal contact and prevent their migration off-site through water or wind erosion.

The seepage of acidic waters rich in heavy metals was identified as a potential problem during Phase I of the ERA. Mitigation of this seepage through installation of a drainage system is beyond the scope of the ERA but could be installed as part of the long-term remedy for the site subsequent to construction of a retaining wall without any additional cost.

Cost and Schedule

The cost to implement any of the alternatives analyzed ranges between \$467,600 and \$553,800. With an upper limit of \$1 million, up to \$532,400 could be available for additional ERA action within the 6-month timeframe. Time required for construction of the alternatives ranges from 4 to 5 months.

Institutional Considerations

Institutional issues addressed in the EE/CA for the Gregory

Incline and Tailings site included permit requirements, responsible party considerations and community relations.

Investigators identified two permits typically required for the type of construction proposed for the ERA alternatives under consideration for this site. These are a U.S. Army Corps of Engineers, Section 404 Individual Permit for dredge and fill in waterways and a Colorado Department of Health, Section 401 Water Quality Certification and construction dewatering discharge permit. The site may be exempt from some on-site permit requirements because of its status as a CERCLA site.

To address community relations, a fact sheet on the ERA for Gregory Incline and Tailings was prepared for distribution after issuance of the EE/CA report, with a 3-week comment period. CDM also coordinated with the owner of the site in discussion of the approach to be taken in the analysis of the ERA alternatives.

The results of the EE/CA are documented in the EE/CA report completed in June 1986. The report includes a summary matrix addressing the following for each alternative:

- Estimated construction cost
- Estimated construction time
- Technical concerns
- Construction concerns
- Compatibility with final remedy

CONCLUSION

Expedited response actions are one of several methods the U.S. EPA is looking at to improve the efficiency and effectiveness of Superfund response actions. By using the remedial contractor to complete non-time critical removal actions at NPL sites, the removal can be accomplished with minimal interruption of the remedial cleanup effort. This also will minimize confusion or complications resulting from having multiple contractors on-site. It is likely, however, that there will be occasions when multiple contractors must be used to address different issues at the site. In these situations, the RPM and OSC must coordinate closely to keep site operations as efficient as possible.

The results of several ERAs currently underway will be analyzed to assess the effectiveness of ERAs in achieving site cleanups. Based on experience gained at these sites, guidance under development by the U.S. EPA will be modified to improve the process for the technical approach and procedures for coordination between the removal and remedial programs.

Data Quality Objectives Development for Remedial Investigation/Feasibility Studies

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ABSTRACT

Remedial investigation/feasibility studies (RI/FS) are undertaken to determine the nature and extent of the threat presented by the release of hazardous contaminants which would cause substantial danger to present or future public health, welfare or the environment. In these studies, scientists and engineers evaluate remedial actions that would prevent or minimize contaminant migration. Remedial investigations are comprised of data collection and evaluate the extent of contamination. To ensure that the data generated during the remedial investigation are adequate to support a decision, a clear definition of the decision and the method by which it will be made must be established early in the planning of each RI/FS. These determinations are facilitated through data quality objectives (DQOs) development.

DQO development is a dynamic process involving decisionmakers and project managers, with input from appropriate technical staff. The total uncertainty associated with these decisions can be determined by evaluating data collected and analyzed in conformance with the DQO process. Total uncertainty includes both sampling error and analytical measurement error.

DQOs are established prior to data collection and are critical in developing a sampling and analytical plan consistent with CERCLA program objectives. DQOs are developed to address the specific requirements of the individual sites and are based on the intended uses of the data.

The DQO process assures the development of a formal plan describing the level and extent of sampling and analysis required to produce enough data to evaluate the remedial alternatives for a site. Site-specific DQOs are incorporated in sampling and analysis plans. DQO development approach is presented here in order to improve the overall quality and cost-effectiveness of data collection and analysis activities in RI/FS activities.

INTRODUCTION

In order to ensure that the data generated during remedial investigations are adequate to support decisions regarding remedial action at an uncontrolled hazardous waste site, these decisions and the methods by which they will be made must be clearly defined early in the planning of the remedial investigation/feasibility study (RI/FS). Data quality objectives ensure that the environmental data collected to support an Agency decision are of known and documented quality. These statements may be qualitative or quantitative and are specified prior to data collection activities. DQOs are identified during the RI/FS scoping process and during development of sampling and analysis plans.

Data quality objectives are developed through a three-stage process illustrated in Fig. 1. Although the three stages are identified and discussed sequentially, they are undertaken in an interactive and iterative manner whereby all the elements of the DQO process are continually reviewed and applied during the RI/FS. DQOs are developed at the onset of an RI/FS project and revised or expanded as needed based upon the results of each data collection activity.

STAGE 1—IDENTIFY DECISION TYPES

Stage 1 of the DQO process is undertaken to identify the individuals responsible for decisions, to identify and involve data users and to define the types of decisions which will be made as part of each site-specific RI/FS. The major elements of Stage 1 are presented in Fig. 2.

Identify and Involve Data Users

Although identification and involvement of data users is listed as the first step in Stage 1 of the DQO development process, it is a continual process throughout the RI/FS. As new information on a site is gained, the specific areas of expertise required to complete the RI/FS can be better defined.

The remedial project manager (RPM), as defined in the NCP Section 300.6 (*Federal Register 50* No. 224), is the federal official designated by the U.S. EPA or another lead agency to coordinate, monitor or direct remedial or other response activities under the NCP. The RPM and the RI/FS contractor site manager are the key decision-makers for the DQO development process. They are responsible for ensuring that appropriate data users are involved in the RI/FS process and that DQOs are developed. The major responsibility for incorporating DQOs into planning and implementation activities lies with the RI/FS contractor.



Figure 2 DQO Stage 1—Identify Decision Types







INCREASING DATA QUALITY/QUANTITY

Figure 4 Relationship of Risk and Data Quality/Quantity

Evaluate Available Information

Available site information is reviewed and evaluated as an initial step in the RI/FS process. This review provides the foundation for additional on-site activities and serves as the data base for RI/FS scoping. Data should be evaluated at the initiation of an RI/FS and at each stage within the RI where additional data

Develop Conceptual Model

The conceptual model provides a description of the uncontrolled hazardous waste site and its environs which is used to develop hypotheses regarding the contaminants on-site, their routes of migration and their potential impact on sensitive receptors. Conceptual models may include components from computer models, analytical models, graphic models and/or other techniques. The hypotheses are tested, redefined and modified during the course of the RI/FS. The conceptual model should be detailed enough to address all potential or suspected sources of contaminants, types of contaminants and concentrations, affected media, rates and routes of migration and receptors.

The conceptual model may be expanded as additional site information is obtained and, in some cases, may serve as the starting point to develop a computer or statistical site model.

Specify RFI/FS Objectives

In a broad sense, the objective of an RI/FS is to determine the nature and extent of the threat posed by the release or threat of release of hazardous substances and to select a cost-effective remedial action to minimize the risk of migration of or exposure to contaminants. Achieving this broad objective requires several complicated and interrelated activities, each having its own objectives, acceptable levels of uncertainty and attendant data quality requirements. The expression of these objectives in clear precise statements is the first step toward the development of a costeffective program to collect sufficient data for decision-making. This step of the DQO development identifies the decision-making process, the decision types and any additional data needed to complete an RI/FS.

Defining the types of decisions which will be made regarding remedial actions for uncontrolled hazardous waste sites requires a clear understanding of the problems posed by the site and an awareness of the consequences of making a wrong decision. The consequences of a wrong decision must be weighed for each major decision made during the RI/FS process. Where the consequences of a wrong decision carry significant public health, safety or environmental impacts, greater attention must be paid to obtaining the data required to ensure a sound decision.

The information available for making a decision is related to the risk of making a wrong decision and the significance of the consequences. As shown in Fig. 3, as the quantity and quality of data increase, the risk of making a wrong decision decreases. This is not a true inverse relationship; at some point, the collection of additional data or improvement of data quality will not significantly increase overall data quality. This can be expressed best on a graph (see Fig. 4). The risk of making a wrong decision decreases as data quantity and quality increase until it reaches a point of diminishing returns, where additional data or increased quality of data do not significantly reduce the risk of making a wrong decision.

Data quantity and data quality are independent variables which must be considered jointly when assessing the consequences of making a wrong decision. Collecting increased quantities of low quality data may not reduce the risk of making a wrong decision. Likewise, increasing the data quality of a limited number of samples may not add significantly to the body of knowledge to be used in making a decision.

The value of obtaining additional data or increasing data quality traditionally has been based on professional judgment for RI/FS projects. The intent of the DQO process is to support such decisions with a more systematic approach to evaluating the risk associated with wrong decisions and to determining the levels of uncertainty associated with decisions.

As part of the development of the objectives for the RI/FS, the decision-making process should be outlined. Specific decisions that will be made, when they will be made and by whom they will be made, are critical parts of the outline development. Critical decisions need to be considered when defining the data to be collected, the sampling and analytical methods, the sensitivities of the methodologies and the method detection limits. The adequacy of the data which will be collected during the RI/FS to meet the overall project objectives must therefore be evaluated in Stage 1 of the DQO process. The result of Stage 1 is a determination of the sufficiency of the existing data to meet the RI/FS objectives. If the existing data are sufficient, there is no need to collect additional data. If the data are insufficient, the types, quality and quantity of data which must be collected will be determined in Stage 2.

STAGE 2—IDENTIFY DATA USES/NEEDS

Stage 2 of the DQO process is undertaken to define specific data uses and to specify the types of data needed to meet the RI/FS objectives. The major elements of Stage 2 of the DQO process are identified in Fig. 5.

Identify Data Uses

A detailed evaluation of data uses is undertaken in Stage 2 to ensure that the amount of data (number of sampling points and frequency of sampling) and quality of data (field sampling and



Stage 2-Identify Data Uses/Needs

analytical methods and method detection limits) are appropriate for their intended use. Uses for these data can be developed by evaluating the general use category for which data will be obtained, such as health and safety, site characterization, risk assessment, alternatives evaluation, remedial action design or potentially responsible party (PRP) determination.

Data use categories define the general purposes for which data will be collected during the RI. By defining the intended uses for the data early in the RI scoping process, one can develop a concise statement regarding the type of data needed.

Data Types

Data types may be specified initially in broad groups such as background samples or media samples. Then the data may be refined to a more detailed level to ensure that data obtained are useful in meeting the objectives of the RI/FS. The process should be followed for each medium of interest or each source material. Completing the entire decision matrix results in specifying the data type needed for each intended data use.

Since environmental media and source materials are interrelated at uncontrolled hazardous waste sites, data types used to evaluate groundwater contamination can also be used to evaluate soil contamination. By identifying data types by medium, the decision-maker and the data users can discuss overlapping data needs to refine the scope of the RI.

The types of analyses which will be performed on each sample must be determined while identifying data types. The analytical requirements are dictated by the use of the data, which ultimately is driven by the remedial alternative which is under consideration.

The data types specified in Stage 2 not only should be limited to chemical analytical parameters, but also should include physical parameters such as permeability and porosity, which are needed to evaluate contaminant migration. The level of detail to which data types are defined during the DQO process must be sufficient to evaluate sampling and analysis options during subsequent DQO stages.

Evaluate Sampling and Analysis Options

One can evaluate sampling and analysis options only after all components or subsets of the sampling and analysis options are identified. The components of a sampling and analysis plan include the individual sample collection and analysis procedures which will result in the data types specified. For example, to provide data on the concentration of volatile organics in a monitoring well, one must identify sampling procedures which will result in a representative sample and analytical methods which will yield the desired results.

Developing a sampling and analysis approach, which ensures that appropriate levels of data quantity and quality are obtained, usually can be accomplished using a phased RI approach and field screening or remote sensing spproaches to direct the data collection activities. By subdividing the data collection program into a number of phases, the data can be obtained in a sequence which allows them to be used to direct subsequent data collection activities.

The resources available to perform a RI/FS must be evaluated during the scoping process. Within Stage 2 of DQO development, the time, personnel resources and equipment required for obtaining data are considered.

Cost savings can be achieved by performing multiple media sampling activities simultaneously (e.g., sample groundwater and surface water at the same time) or by separating sampling into phases to better target sample collection. When considering personnel, one should determine if special training is required to undertake certain field sampling or laboratory analysis tasks. This evaluation is most effectively performed as sampling and analysis options are identified.

Identify Data Quality Needs

Data quality needs can be identified best by establishing performance and cost criteria. Performance criteria can be used to establish action limits above which remediation or removal is deemed necessary. Design criteria are used to determine if cost estimates for remedial alternatives fall within acceptable ranges.

In specifying any criteria on which to base decisions, action levels and the acceptable risks should be considered. The action level specifies a concentration above which some action will be taken. For example, an action level can be used during the FS to make decisions regarding areas requiring remediation. Determination of action levels is currently a site-specific activity. The decision-maker, with input from data users, determines the appropriate action level for the site. The acceptable risk specifies the chance of exceeding the action level which is acceptable to the decision makers.

U.S. EPA feasibility studies guidance' states that the cost of remedial alternatives should be determined to within +50% and -30% of the actual cost. This statement not only puts requirements on the type and amount of data which must be collected during the field investigation, but also requires the decisionmaker to consider potential remedial alternatives before planning the field investigation.

Identify Data Quantity Needs

The number of samples which should be collected for an RI activity can be determined using a variety of approaches. The validity of the approach utilized is dependent on the characteristics of the media under investigation and the assumptions used to select sample locations. The greater the quantity of data available for making a decision, the higher the chances for obtaining data which address the RI/FS objectives. In situations where data are limited or unavailable, the RI should be developed in a phased approach to allow collection of initial samples to characterize the general conditions at the site. These data then can be used to help select the appropriate number of samples to be obtained in subsequent phases of the RI.

Specify PARCC Goals

Data quality requirements for a given program or activity can be specified by using the precision, accuracy, representativeness, completeness and comparability (PARCC) parameters.

PARCC goals should be developed based upon the level of certainty required in the data. Historical precision and accuracy data for analytical laboratories being considered during the RI/FS scoping process should be reviewed in order to evaluate adequacy for intended use.

If the level of precision and accuracy historically generated by a laboratory or particular test method is unacceptable, analysis of additional matrix spikes and replicate analysis may be warranted for the sampling and analytical task under consideration. PARCC parameter goals are established in order to have a method to evaluate results. The actual precision, accuracy, representativeness, completeness and comparability of the data can only be fully assessed following collection of the data. If upon review of the analytical data it is determined that the PARCC goals have not been met, the decision-maker must decide if samples are sufficient to make decisions or if re-sampling or re-analysis is warranted. If the PARCC goals have been met, the resulting data should be considered appropriate for the uses specified in the DQO process.

STAGE 3—DESIGN DATA COLLECTION PROGRAM

Stage 3 of the DQO process is undertaken to develop and assemble the detailed data collection program for the RI/FS. Through the process of addressing the elements identified in Stages 1 and 2, all the components required for completion of Stage 3 should be available for compilation. Stage 3 entails assembling the data and developing documentation.

The DQO development process is initiated during RI/FS scoping and is completed in conjunction with the development of a work plan, sampling and analysis plan and quality assurance project plan (QAPjP) addressing each RI/FS phase. The various stages of the DQO development process are interactive in nature. As additional details regarding the site are discovered during the scoping process, the decisions which will be made during the RI/FS are further refined. This refinement of decisions allows for further specification of data needs and for design of the data collection program.

Assemble Data Collection Components

During Stage 2, specific DQOs have been developed by media or sampling activity. The intent of Stage 3 is to compile the information and DQOs developed for specific tasks into a comprehensive data collection program.

The data collection components should be developed for all sampling tasks and phases. During this process, a detailed list of all samples to be obtained should be assembled in a format which includes RI phase, media, sample type, number of samples and QA/QC samples (type and number). In addition, a schedule for all sampling activities should be developed in bar chart or critical path method format.

Develop Data Collection Documentation

Developing DQOs in a formal manner ensures that the appropriate data are obtained in order to meet the objectives of the RI/FS. Data collection documentation requirements vary on a regional basis within the U.S. EPA RI/FS program. The output of the RI/FS DQO process is a well defined sampling and analysis plan based on data needed to make decisions. The DQO process also will allow the scope and costs for work plans to be developed on a sound decision-based approach.

CONCLUSIONS

The DQO process provides a framework to ensure that all the pertinent issues related to data collection are addressed. Through the process of developing DQOs, the level of uncertainty associated with a data set can be established. RI/FS data are collected for a variety of uses and data of differing qualities are required for each specific use. The highest quality obtainable data seldom are required for all activities. What is required, however, is that the quality of all data collected be known and documented. This procedure allows the most efficient use of resources by defining a given data quality need and selecting an analytical support option that, when integrated with a specific sampling approach, will produce data of the quality needed. By determining the quality of the data which have been collected, the decision-maker can draw conclusions and make decisions with a specified degree of certainty. Additional information about DQOs may be obtained from guidance under development by the Office of Solid Waste and Emergency Response.³

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An Approach to Remediating Contaminated Bedrock Aquifers

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ABSTRACT

A major problem to the restoration of abandoned hazardous waste disposal sites relates to the remediation of contaminated bedrock aquifers. A critical element in the successful remediation of these aquifers is the ability to identify and evaluate migration pathways through the bedrock. There are a variety of analytical procedures that the geologist/engineer can employ to assist in identifying these principal migration pathways. These available tools will be identified through a series of site specific case studies.

The basis for developing the migration pathways lies in the conduct of well-structured field investigation programs including the application of specific geophysical techniques. The information gathered during the geophysical survey is then employed to both supplement and direct the boring and monitoring well installations.

The data collected during the initial field investigation are used to construct three-dimensional rock block diagrams necessary to design the pumping test required to verify fracture patterns within the aquifer system. The proper location of fracture sets including information upon interconnection is then employed to evaluate aquifer response characteristics under different groundwater extraction scenarios.

The verification of the aquifer response characteristics under localized pumping is the first step in the successful development of a groundwater remediation program for bedrock contamination.

INTRODUCTION

The approach to the hydrogeologic investigation and subsequent remediation of the contaminated aquifer depends on the physical characteristics of the site. Two sites, referred to as Site 1 and Site 2, have varying physical characteristics. Therefore, a variety of geophysical techniques were used to obtain the structural and hydrologic data necessary to define contaminant migration pathways within the bedrock aquifers.

The hydrogeologic investigations at these sites were conducted in phases, each built upon the information from the previous phase. In Phase I of any hydrogeologic investigation, all previous reports, studies, maps, aerial photos and records are reviewed. The least costly investigative techniques that will provide useful information are conducted in Phase I of the field investigation; the following techniques frequently are used to provide some site specific data for relatively little expense:

- A fracture trace analysis to determine the primary and secondary fracture orientations as well as the type of bedrock at the site
- A seismic refraction survey, which will provide the depth to the water table, the thickness of various lithologic units and the

topography of the bedrock underlying the site

- Sampling and analysis of existing wells or potential contaminant source areas to evaluate the magnitude of the contamination problem at the site
- Geophysical logging (i.e., resistivity, caliper, temperature, conductivity and self-potential) of existing boreholes on-site to provide information on the depth of fracturing, rock quality and zones that transmit water

The Phase I results of the hydrogeologic investigation are used to analyze the various physical characteristics at the site in order to design the appropriate Phase II investigation. The objective of this phase is to collect the necessary data to construct a threedimensional rock block diagram of the site. The rock block diagram is based on data from the installation, sampling and analysis of monitoring wells and the results of more complicated and costly geophysical surveys, which may include the following:

- Acoustic televiewer logging, which provides information on the depth and orientation of fractures within the borehole
- Vertical seismic profiling, which provides information on the depth, orientation and hydraulic conductivity of the fractures
- Geotomography (cross borehole electro magnetics), which provides information on the depth and orientation of fractures between the boreholes
- Oriented drilling, which provides information on the rock type and quality as well as the depth and orientation of the fractures intersecting the borehole

It is important to note that the above geophysical techniques yield similar information. The decision whether to use one of these or other techniques will be determined by the physical characteristics at the site and the Phase I data collected. Both vertical seismic profiling and geotomography provide data on fracture orientation some distance away from the borehole, while the acoustic televiewer does not. The acoustic televiewer, however, was used at Site 1 because Phase I information revealed that the fractures were steeply dipping which lowers success with vertical seismic profiling (a refraction technique). The acoustic televiewer was less empensive than the geotomography at this site.

At Site 2 there were more data and information available pertaining to the site; the upper zone (0-20 ft) of the bedrock was highly weathered and fractured. Thus, the bedrock aquifer was capable of transmitting water as a porous medium would. Due to a breakdown of the acoustic televiewer, pumping and packer testing were used to help determine the contaminant migration pathways in the bedrock aquifer at Site 2.

Phase III relies on the contamination information, bedrock geology, hydrogeologic information and rock block diagram to

indicate the appropriate locations to conduct pumping tests. The pumping tests verify the major fracture sets within the aquifer as well as the interconnection of these fracture sets. The information on the interconnection of fracture sets is employed to evaluate aquifer response characteristics under different groundwater extraction scenarios. The various extraction scenarios are used to develop a successful groundwater remediation program for the contaminated bedrock aquifer.

HYDROGEOLOGIC INVESTIGATION RESULTS FOR SITE 1

The Phase I investigation revealed that dumping of bulk liquids took place in two general locations 0.5 mile apart. High levels (up to 10 ppm) of volatile organic compounds were found in the overburden and bedrock aquifers in these areas as shown in Fig. 1. A bedrock supply well for an apartment complex, which is located in a direction perpendicular to the flow gradient, became contaminated.

The bedrock in the study area consists of a meta sedimentary schist with a low porosity and permeability. The estimated hydraulic conductivity varies from 1×10^{-5} to 1×10^{-7} (cm/sec), which indicates that flow through the rock would be insignificant. Thus, the major flow of groundwater must be through the fracture system. The major fracture sets in the area trend N 57 E and are nearly vertical. A major structural feature in the area is a fault that passes close by the site which is oriented in a N 50 E direction. This fault caused the sympathetic fracturing of the formation at the site, i.e., the fractures on-site are similar in orientation to the nearby fault. 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 was found to trend northeast at the site. Results from the geophysical logging indicated that the majority of the fracturing and water bearing fractures are located in the upper 100 ft in the bedrock aquifer. This finding saved costs in the drilling of Phase II monitoring wells because they were required to reach a depth of 100 ft rather than 300 ft, which was the depth of the previously installed wells. Results from the seismic refaction survey indicated the bedrock to be at a depth of 2 to 30 ft across the site with a water table sloping slightly to the south and southeast. The velocities were as expected for a schist, but the defining of a uppermost weathered zone was difficult due to the thin layer of basal till overlying the bedrock.

Phase II of the investigation consisted of strategically locating additional monitoring well clusters, logging them with an acoustic televiewer with further sampling and analysis of the on-site groundwater. The results indicated a potential for the bedrock supply well serving the apartment complex to be interconnected with one of the source areas. It was anticipated that the pumping of a deep bedrock well in the vicinity of the second source area would control the groundwater flow in the vicinity of this source area. Widespread contamination from volatile organic compounds was found predominantly in the bedrock aquifer as shown in Fig. 1. A rock block diagram was developed that delineated promising locations at which to conduct pumping tests.

Phase III consisted of the results of two pumping tests and an additional sampling round of on-site groundwater. The pump test data suggested linear flow in a fractured rock aquifer, where the pumped fracture acts much like a collector well. The drawdown is not radial, but there is a trough-like depression in the water table parallel to the pumped fracture as shown in Fig. 2. It was verified that the areas of contamination in the bedrock could be controlled by pumping two rock wells. The flow in the bedrock is controlled by fracture sets oriented northeast southwest, although the horizontal gradient is to the south and southeast. The troughs of depression created by the two pumping tests are oriented northeast, which coincides with the fault in the site area and fracture trace analysis. Even during non-pumping conditions, the contaminants were found to migrate from northeast to southwest. The information collected indicates that a pumping and treatment scenario at the southwest deep rock well in Source Area 2 could be readily implemented. Appropriate remedial action in connection with contaminated soils would shorten the operational time frame for such remedial action.



Figure 1 Site Map Indicating Estimated Source Areas of Contamination and Location of Selected Pumping Wells



Figure 2 Trough Like Depression Created in Potentiometric Surface in the Vicinity of a Fracture

HYDROGEOLOGIC INVESTIGATION RESULTS FOR SITE 2

The Phase I investigation revealed that dumping of bulk liquids, landfilling of drums, sludges, construction debris and tires took place in a highly permeable (sand and gravel) kame deposit. The stratified drift (kame) deposits are located in the lowlands between north-south oriented highlands.

The bedrock in the study area consists of a meta-sedimentary gray colored gneiss. A diorite dike which trends north-south along the eastern border of the site was identified in previous bedrock maps as shown in Fig. 3. In general, the bedrock exhibits a north-south fracture pattern. In the vicinity of the site west of the dike, the fractures dip 30° to the east. To the east of the dike, a contact between the formation underlying the site and a younger formation is indicated. This younger formation has fractures dipping steeply to the west.

Past studies indicated a flow to the north in both the overburden and bedrock aquifer from the land disposal area. The bedrock was highly fractured and weathered, providing the majority of groundwater from the upper 20 to 40 ft of the rock. The upper zone of rock had a similar porosity and hydraulic conductivity to that of the porous medium such as a fine sand. Gneiss is similar to a shist; the zones of higher conductivity often lie parallel to the foliation, which trend north-south at the site. The seismic refraction survey results indicated that the rock was highly weathered and was at a depth of 5 to 25 ft below ground surface. The water table slope was to the north then east away from the land disposal area. The dike registered a high velocity indication that it has a competent surface with little weathering or fracturing. A ground penetrating radar investigation revealed several areas of buried drums and the delineation between the disturbed and undisturbed soil boundaries. In addition, a magnetometry survey was conducted to determine the exact location of the diorite dike and locate potential fracture zones in the gneiss which could serve as contaminant migration pathways. The dike exhibited 600 gamma (a unit of magnetic flux) differences above that of the earth's total magnetic field. The instrument used is capable of determining a one gamma difference and was easily capable of mapping out the diorite dike, which contains mafic minerals.

Phase II of the investigation consisted of strategically locating additional monitoring wells to the west, to the east and directly in the dike. Short duration pumping and packer tests were performed in four rock wells. The sampling and analysis of the entire monitoring well network was conducted to determine contaminant movement through the aquifer over time. Since a previous investigation had been conducted, only two phases of this investigation were required to construct a rock block diagram and perform pumping tests to verify the fracture patterns on-site.

The results of Phase II of the investigation indicate that the dominant feature impacting groundwater flow is the diorite dike bordering the east side of the valley in which the site is located. The general direction of groundwater flow for the overburden and bedrock aquifer at the site is shown in Fig. 4. Note that the groundwater table to the west of the dike has a low water table gradient of 0.005 ft/ft. This gradient results from the dike retarding the groundwater flow and the flat topography of the valley floor, which causes a back water west of the dike. East of the dike, the groundwater gradient is (0.025 ft/ft), five times that west of the dike.



Figure 3 Site Location in Relation to the Dike



Figure 4 Groundwater Elevation Contours in Bedrock

The hydraulic conductivity (K) estimated in several bedrock wells west of the dike exhibited higher values than the kame deposits. Most of the groundwater in the bedrock aquifer is derived from the upper 50 ft in many of the on-site monitoring wells. A well drilled approximately 90 ft into the dike had the lowest K of all the wells on-site and was only producing 8 gal/day.

Pumping test results from two bedrock wells did not display the linear drawdown but a radial drawdown that occurs in a permeable sand and gravel deposit or highly fractured and porous bedrock.

The contaminants were found migrating from the land disposal area north then eastwards toward the bedrock dike (Fig. 4). Moderate levels of total volatile organics (less than 1 mg/l) were found in groundwater at the western edge of the dike. A low level (approximately 40 ug/l) of total volatile organics was found in one bedrock well east of the dike. Groundwater and contaminants can migrate through and over the dike, but the dike has retarded the migration considerably due to its low K and location in the valley.

This information indicates that a groundwater pumping and treatment scenario could be implemented west of the dike as a remedial action. Appropriate remedial action in connection with the contaminated soils would shorten the operational time of such remedial action.

CONCLUSIONS

Sites 1 and 2 were selected as examples because of the substantial differences in the migration of contaminants from the source areas due to the physical characteristics of the sites, especially the bedrock geology.

At Site 1 contamination of the groundwater was caused by improper land disposal of hazardous waste liquids. The flow of groundwater is controlled by the major fracture sets within the site area oriented northeast-southwest. This results in a flow perpendicular to the flow potential (hydraulic) gradient in the overburden aquifer. The investigation focused on determining the depth of water bearing fractures and their orientations via a fracture trace analysis, geophysical logging of the wells and two pumping tests. The data from the investigation indicated that the contamination in the rock could be controlled by pumping two deep rock wells that were installed in the fracture sets which intersect the source areas of contamination.

At Site 2 the groundwater contamination was caused by improper land disposal of hazardous waste. The groundwater flow is strongly influenced by the location of a diorite dike that borders the eastern side of the valley in which the site is located.

The groundwater flow direction in the upper bedrock is similar to that of the overburden. This conclusion was substantiated by the results of pumping tests and a bedrock groundwater elevation contour map of the site. The investigation focused on determining the effects of the bedrock geology on the groundwater flow and contaminant transport via above ground geophysical surveys (ground penetrating radar, electromagnetics and seismic refraction) and down well geophysical techniques (pumping and packer tests and pumping and recovery tests). The results from these investigations indicate that contaminants flow with the groundwater north then east from the land disposal area. The transport of contamination in the bedrock through the dike is significantly retarded due to its lower permeability. In addition, to the west of the dike, the contamination is contained in an area with little vertical or horizontal hydraulic gradients that drive the flow. The results of this investigation indicate that the implementation of a pumping and treatment scheme west of the dike is viable to contain and treat the contaminated groundwater leaving the source area.

Impact of the New Superfund On the Remedial Action Program

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ABSTRACT

This paper reviews the proposed cleanup provisions of Superfund reauthorization. A brief overview of the existing Superfund remedial program is provided as background. Reauthorization provisions that will impact the current program are reviewed and specific technical requirements are discussed. Topics covered include preferences for permanent technologies and use of alternatives to land disposal, applicability of Federal and state requirements for on-site actions and requirements for acceptable off-site facilities. When appropriate, impacts of the new technical requirements are summarized.

INTRODUCTION

In the first 5 years of the Superfund program, the U.S. EPA was faced with a major national environmental problem—protection of public health and the environment from hazardous substances found at uncontrolled hazardous waste sites. Armed with the new statutory authority of CERCLA, the U.S. EPA implemented a program to prioritize the worst sites, investigate their threats, evaluate and select cost-effective remedial actions and design and undertake cleanup. To do this, the U.S. EPA developed a response program that combines Federal, state and private sector resources. A variety of complex technical, legal and policy issues had to be dealt with. Engineers and scientists in the government and private sectors have brought together expertise in disciplines such as hydrogeology, toxicology, risk assessment, environmental modeling, process engineering and regulatory analysis.

Thus far, the Superfund effort has resulted in listing over 800 sites on the National Priorities List (NPL), remedial investigations and feasibility studies (RI/FS) at over 400 sites and cleanup projects at 47 sites, Response activity will be shifting from the study phase to the cleanup phase as RI/FS are completed and more sites are ready for cleanup.

When the original Superfund legislation was passed in 1980, Congress and the U.S. EPA recognized that the \$1.6 billion fund established for cleanup was inadequate to deal with the magnitude of the nation's uncontrolled hazardous waste site problem. For the past 2 years, Congress has been working to draft revised legislation needed to replace the original CERCLA after its taxing provisions expired in late 1985. A number of complicated issues are being addressed during Superfund reauthorization, including:

- Size of the fund
- Source of revenue for the fund
- Requirements for the remedial program
- Cleanup standards
- Standards and scheme for liability

The long and complicated reauthorization process extended

beyond expiration of CERCLA and, at the time of this writing, is still continuing. A number of issues have been resolved by a House and Senate conference committee, and reauthorization is expected in the near future.

Size of the Fund/Mandatory Schedules

This paper focuses on the potential new technical requirements that will impact the conduct of remedial investigations and feasibility studies at Superfund sites. A brief summary is presented first of some related provisions that have been agreed to by the conference committee including the size of the fund and mandatory schedules of program activities. This background will be helpful to fully assess some of the impacts that specific technical changes could have on the remedial program.

Reauthorization will increase the original Trust Fund level of \$1.6 billion to a level of \$8.5 billion over 5 years. Coupled with the increased funding level is a requirement for the U.S. EPA to achieve mandatory schedules for a number of program targets (Table 1). The U.S. EPA has been expanding its current program capacity to anticipate this increased schedule of activities. However, the effort required to meet the proposed mandatory schedules will be increased as a result of incorporating new technical provisions into the current remedial process. These schedules will create new challenges for managers in both the government and private sectors responsible for implementing the program. The following section summarizes some of the proposed reauthorization provisions that could modify the current process.

Table 1 Mandatory Schedules

- All preliminary assessments completed by Jan. 1, 1988
- All site inspections completed by Jan. 1, 1989
- Start 275 new RI/FS within 3 years
- Start a total of 650 new RI/FS within 5 years
- Start 175 new remedial actions within 3 years
- Start 200 new remedial actions during years 4 to 5

Note: All references to time frames are from date of enactment of reauthorization.

SUMMARY OF PROPOSED CLEANUP PROVISIONS

Background of Existing Program

Several provisions of the original CERCLA and implementing regulations promulgated in the National Contingency Plan (NCP) are reviewed here to lay the framework for evaluation of potential new requirements of Superfund reauthorization. The original CERCLA (of 1980) provides limited direction regarding selecting remedial actions. A remedial action is defined as an action consistent with permanent remedy that prevents or minimizes the actual or potential release of hazardous substances.

Remedial actions should prevent substantial danger to present or future public health, welfare or the environment. In addition, off-site disposal of hazardous substances is allowed only if certain determinations are made, thereby creating an implied preference for on-site response. Remedial actions are required to be consistent with the NCP to the extent practicable, to be cost-effective and to provide protection of public health, welfare and the environment.

CERCLA also requires off-site disposal to be at facilities in compliance with the Solid Waste Disposal Act (i.e., RCRA). However, the Act did not specify cleanup requirements for on-site response actions.

The NCP promulgated on July 16, 1982, established a response framework by describing the steps for setting priorities among sites, taking emergency (removal) actions and evaluating remedial actions. The NCP defined cost-effectiveness in terms of the "least cost" alternative providing adequate protection to public health, welfare and the environment. However, for a number of reasons, the NCP did not provide direction on the extent or level of cleanup attained by remedial actions.

As the U.S. EPA gained experience with remedial actions, the NCP was revised and additional guidance was provided on remedial investigations and feasibility studies. The general effect was to begin moving the program away from the "least cost" approach which often favored containment or land disposal and toward increased use of treatment and destruction technologies. The revised NCP dated Nov. 28, 1985, modifies the previous definition of cost-effectiveness by explaining that cost is only one of several factors to be considered when selecting a remedy. This provision allows the selection of potentially more expensive treatment alternatives that provide better long-term protection and effectiveness than other alternatives such as land disposal. The revised NCP also set a requirement that remedial actions generally be consistent with the requirements of other environmental laws.

The Superfund reauthorization provisions on cleanup requirements adopted by the conference committee take the U.S. EPA policy a step further. These provisions mandate specific requirements for selecting remedial actions and providing direction on how the U.S. EPA is to conduct the technical evaluation of remedial alternatives.

New Legislative Requirements

Superfund reauthorization will provide substantially more detail than the original legislation. Proposed statutory language includes a number of new technical requirements and incorporates requirements of the revised NCP in the areas of:

- Encouragement and use of treatment technologies or permanent technologies
- Factors for evaluating alternatives
- Application of Federal and state standards
- Acceptability of off-site disposal facilities
- Involvement of the state in decision-making

A number of the new provisions are consistent with current U.S. EPA procedures and, therefore, will not result in significant program impacts. However, others may require basic changes in the Superfund program. For example, decision rules related to remedy selection and cost-effectiveness will encourage the use of treatment technologies as alternates to land disposal without treatment.

Remedial actions must still be cost-effective and consistent with the NCP, to the extent practicable. However, a hierarchy of preference for remedies is established. Remedies that use treatment technologies that permanently and significantly reduce the volume, toxicity or mobility of contaminants are preferred over other alternatives. When treatment technologies are practicable and available, off-site disposal without treatment is the leastfavored alternative. The selected remedy must still be protective of human health and the environment. But it must also use permanent solutions and alternative technology or resource recovery to the maximum extent practicable. These decisions rules are summarized in Table 2.

Table 2 Summary of Decision Rules for Remedial Actions

- Remedy must be cost-effective and consistent with the NCP to extent practicable
- · Remedy must protect human health and environment
- Preference for permanent and significant reduction of contaminants' volume, toxicity and mobility
- Utilize permanent solutions, treatment or resource recovery to maximum extent practicable
- Off-site land disposal without treatment is least-favored if treatment is practicable and available
- Technologies need not be demonstrated at sites with similar characteristics

Remedial investigations and feasibility studies will have to evaluate alternatives using at least the factors listed in Table 3. This provision may require modification of the RI/FS process to evaluate alternatives in a different way. Increased emphasis will be placed on attempting to assess long-term impacts of containment or land disposal in more detail than has sometimes been the case in the past. Use of bench or treatability studies will increase in order to evaluate how effectively treatment technologies reduce contaminant volumes, toxicity and mobility.

Table 3 Remedy Evaluation Factors

- Long-term uncertainties of land disposal
- Requirements of RCRA
- Persistence, toxicity, mobility and ability to bioaccumulate
- · Short- and long-term potential adverse health effects and exposure
- · Long-term maintenance costs
- · Potential future costs if a remedy fails
- Potential threats from process of off-site disposal or containment

To assess the impacts of new provisions in more detail, it is useful to divide remedial actions into on-site and off-site actions. The following sections will describe potential statutory changes and, when possible, attempt to identify potential impacts on the remedial program.

ON-SITE RESPONSE REQUIREMENTS

Applicable Cleanup Standards

Current U.S. EPA policy requires that on-site remedial actions should comply with the legally applicable and relevant or appropriate requirements of other Federal environmental laws. Limited exceptions from compliance are allowed under specific situations. The revised NCP lists the Federal requirements that may be applicable or relevant and appropriate. For on-site remedial actions, the major practical impact has meant use of RCRA regulations and guidance to formulate and select alternatives.

Proposed reauthorization language will use a similar approach requiring that remedies attain a level of control required by legally applicabale or relevant and appropriate requirements with respect to the specific site situation. Both Federal and state standards, requirements, criteria or limitations are included. Federal standards from the following laws are specifically listed:

- Toxic Substances Control Act
- Safe Drinking Water Act
- Clean Air Act
- Clean Water Act
- Marine Protection, Research and Sanctuaries Act
- Solid Waste Disposal Act (i.e., RCRA)

Any state-promulgated standard, requirement, criterion or limitation that is more stringent than a Federal provision also would apply if the state identifies it to the U.S. EPA in a timely manner. This would include state facility siting laws or laws which implement approved, authorized or delegated Federal programs.

Current U.S. EPA policy is to consider more stringent state requirements as part of the selected remedy. This new provision would formalize that policy and probably mean that remedial investigations and feasibility studies would have to incorporate more stringent state requirements together with Federal requirements into remedial alternatives. This provision would require states to identify their requirements to the U.S. EPA early in the remedial planning process, preferably during the RI/FS scoping phase.

Surface and Drinking Water

Applicable or relevant and appropriate requirements also include use of Recommended Maximum Contaminant Levels (RMCLs) and Water Quality Criteria. Water Quality Criteria have been used in the remedial program to set surface water cleanup targets and, when adjusted to reflect only human consumption, for groundwater cleanup. Therefore, requiring their use should not be inconsistent with current procedures.

However, RMCLs, which are solely health-based indicators, generally have not been used to set cleanup targets. Rather, Maximum Contaminant Levels (MCLs), which have somewhat higher values based on technical and costs considerations, typically have been used when available. Since some proposed RMCLs for carcinogens are set at zero, this requirement may be difficult or expensive to achieve using available technology.

Alternate Concentration Limits

Another potential impact on groundwater remedies deals with setting alternate concentration levels (ACLs). Generally, groundwater cleanup levels will be defined by applicable or relevant and appropriate Federal and state requirements as described above. These levels (e.g., MCLs) must be obtained at the facility boundary defined by the RI/FS. Proposed statutory language will allow alternate concentration levels to be set beyond the site boundary under limited situations. All of the following conditions must be met to establish an ACL under Superfund:

- There is a groundwater discharge to surface water
- There will not be a statistically significant increase in surface water concentration as a result of the discharge
- Enforceable groundwater use restrictions will be provided between the site and surface water discharge

Congress indicated that the RI/FS should collect sufficient background and surface or groundwater data to estimate potential surface water concentrations at a 95% confidence limit. Potential health and environmental impacts from sediments and biota also must be evaluated as part of the ACL process. It is likely that remedial investigation data needs at some sites will be increased to adequately evaluate these requirements. However, these impacts should be limited to sites where surface water is reasonably close to the source of contamination and there is no current or projected groundwater use.

Review of On-site Remedies

If a remedial action will leave contamination on-site, the U.S.

EPA must review the site at least every 5 years to determine if additional response is needed. A list of these sites must be prepared and reported to Congress. This requirement is intended to allow the U.S. EPA to fund either remedial or emergency response in the event that a remedy fails or is less effective than anticipated.

Waivers from Applicable or Relevant and Appropriate Requirements

The U.S. EPA's current policy allows for exceptions from compliance with applicable or relevant and appropriate requirements under specific situations. These situations have been specified in the revised NCP. The existing exception used most frequently to date is based on the action being an interim remedy that will be part of a total remedy not yet completed. Many sites will have several approved remedies dealing with different areas or media (e.g., contaminated soil and contaminated groundwater). The interim remedy exception assumes that the final remedy selected in the future would need to be consistent with other environmental requirements unless another exception were approved at that time. It appears that Congress intends to adopt most of the U.S. EPA's current exceptions and will add additional ones. The proposed exceptions are summarized in Table 4.

Table 4Exceptions for On-Site Remedies

- The remedy is part of a total remedy that will ultimately comply
- Compliance will result in greater risk to human health and the environment
- Compliance is technically impracticable based on engineering considerations
- The selected remedy will obtain an equivalent standard of performance
- Compliance will not provide a balance between protection at the site and the amount in the fund
- For state requirements, the state has not applied or demonstrated the intention to apply the requirements consistently at other similar sites

Potentially the most significant new exception is one that allows an equivalent standard of performance. It appears that this exception would allow flexibility when selecting technologies that could otherwise be required by a Federal or state law, standard or requirement. For example, a state policy may require incineration for organics removal in soil; however, a soil washing and treatment process could be used if the same level of protection were achieved. This exception will not allow a lesser level of protection or a different method of calculating the level. If a standard is technology based, a new performance level cannot be calculated using a risk-based approach, on the assumption that it would result in a lesser level of protection.

Permits

The U.S. EPA's current policy is that Federal environmental permits are not required. Proposed statutory language goes further by stating that no Federal, state or local permits are required for on-site remedies (or other response actions). Since this is not limited to environmental permits, it presumably includes all permits including local building permits. The intent of this is to save time required for permit processing while assuring that the appropriate technical requirements are met through provisions described above.

OFF-SITE REMEDIES

Use of Acceptable Facilities

The U.S. EPA's current policy is to require that off-site facilities receiving waste from Superfund sites have all appropriate permits and that the unit receiving the waste does not have significant RCRA violations or conditions that could result in improper operation of the unit. In practice, each RI/FS will evaluate the type of treatment, disposal or storage appropriate for the site-specific wastes and identify potential facilities. The final decision on the acceptability of a facility generally is made by the U.S. EPA Regional Office during the design phase, after the remedy has been selected. The specific facility often will not be identified until bids have been received and evaluated.

The new provision would require that any contamination transferred off-site would be taken only to facilities in compliance with RCRA, TSCA or other Federal or state requirements. Land disposal is allowed only at a unit that is not releasing contamination to groundwater, surface water or soil. Any release of contaminants from any units at the facility must be controlled by an approved RCRA corrective action program.

This provision appears to limit land disposal to facilities that are fully in compliance with RCRA. Disposal at a unit specially constructed for Superfund waste is not allowed if other existing units are leaking and are not under corrective action. The U.S. EPA is required to notify the facility owner regarding the facility's suitability under these provisions, and the owner is allowed to meet with the U.S. EPA to discuss any findings.

This new provision is essentially consistent with the U.S. EPA's current policy and therefore should not create a significant new program requirement. It appears likely that increased effort to evaluate the acceptability of potential off-site facilities will have to be made during the RI/FS. This provision may create temporary problems with finding acceptable land disposal facilities that do not have releases from any units or have all such releases under approved corrective action programs. The U.S. EPA's experience shows that the number of acceptable facilities is limited in some geographical areas. The possibility for delays in implementation of the remedy may be increased while acceptable facilities are identified.

Land Disposal Within a State

Several specific requirements are imposed for remedial actions that involve land disposal within the state where a site is located. These requirements only apply if land disposal is part of a remedy that does not permanently and significantly reduce volume, toxicity or mobility of the contaminants. In these situations, the remedy used need not comply with a state requirement that could prohibit land disposal in the state. In essence, this provision reinforces the preference for use of technologies that achieve permanent and significant reduction of contamination. However, there are several exceptions that would allow a state-wide prohibition of land disposal to be effective. These are:

- The state requirement is generally applicable and was formally adopted
- The requirement is based on relevant considerations and was not intended to preclude on-site remedies or for other reasons not related to public health and the environment
- The state must arrange for and pay for the additional cost of using a land disposal facility

All of these conditions must apply to allow a state land disposal restriction. However, the condition requiring the state to pay for the additional cost of using an out-of-state facility probably will be the practical consideration.

CONCLUSIONS

Potential Impacts on the Remedial Process

This paper has discussed a number of potential new technical provisions that may be required by Superfund reauthorization. When considered individually, each has varying impacts on the current remedial program. Some provisions are consistent with current U.S. EPA policies and therefore will have no impact, while others will require the program to move in new directions. The impacts can be summarized in two general areas: (1) impacts on the remedial investigation and feasibility process; and (2) impacts on the types of remedial actions selected.

Impacts on the remedial investigation and feasibility study process will result in procedural changes that translate to cost and time impacts. Table 5 summarizes some of the potential impacts on RI/FS. Overall, there should be an increase of both the cost and time of RI/FS due to the need to conduct treatability studies for alternate or permanent technologies and to comply with more stringent state requirements. The extent of these increases is difficult to assess without implementation experience, but likely will be proportional to the complexity of site considerations such as number and type of contaminants, contaminated media and availability of proven treatment technologies.

Table 5 Potential RI/FS Impacts

Provision	Potential Impact			
	Time	Cost		
Revised Cost- Effectiveness Procedures	Some increase due to more extensive alternatives evaluation	Some increase due to more extensive alter- natives evaluation		
State Standards	Some delay for notification of the U S EPA	Increase cost to com- ply with more stringent standards		
Alternate Concentration Limits	Increase to collect addi- tional field data at some sites	Increased data col- lection and evaluation costs		
On-site Permits	Decrease since no permits are needed	No change		
Off-site Facilities	Minimal increase since requirements are consistent with current policy	Minimal or no increase		
Preference for Permanent Remedies	Increase to test applica- bility of technologies	Increased cost of treatability studies and evaluations		
		Increased costs of selected remedies		

The impact these new Superfund provisions will have on the types of remedies selected are potentially greater than impacts on the RI/FS projects. The U.S. EPA has been moving away from land disposal and approving more treatment and destruction remedies. That direction is certainly strongly encouraged by the new provisions and potentially will lead to the selection of more expensive treatment remedies. Many of the rules and preferences contained in the reauthorization language are "qualified" to potentially allow the U.S. EPA some degree of judgment for their application when selecting remedial actions. For example, consider the requirement to select remedies that are permanent and use alternate technology or resource recovery. It is "qualified" by adding to the maximum extent practicable. This may give the U.S. EPA flexibility to deal with the complicated, site-specific problems posed by uncontrolled hazardous waste sites. However, the U.S. EPA will have to interpret congressional intent as to how much flexibility will be allowed. Regardless of how these decision rules and preferences are implemented in U.S. EPA policy and guidance, many complex technical and policy issues must be resolved each time a remedy is selected at a Superfund site.

Improved Project Execution

It is clear that the Superfund remedial program will face increased challenges to effectively implement these new provisions. One significant impact will be the increased pressure placed on those government and private sector managers who are responsible for conducting remedial investigations and feasibility studies at Superfund sites. The new technical requirements will add complexity and increase both time and cost of conducting projects. Pressure will increase to find new and innovative ways to complete projects within reasonable budget and time constraints in order to attain congressionally mandated schedules. New and largely unproven technologies will need to be applied to the wide range of contaminants and media found at Superfund sites. Difficult decisions will have to be made with limited information on technology reliability and performance. Much of the responsibility to meet this challenge will fall to the engineering profession. Engineers in Federal, state and local governments and engineers in the private sector will have to combine their efforts and utilize the expertise of each group to be successful.

Note:

The analysis of new provisions in this paper may be modified by final CERCLA reauthorization. This paper has not been peer reviewed by the U.S. EPA and does not represent the policy or position of the U.S. EPA.

Superfund Revisited

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ABSTRACT

The implementation of remedial actions at a Superfund site is not a guarantee against further review. In the early 1970s a chemical producer was ordered by the State Regulatory Agency to remove sludge from a basin. The sludge was solidified and placed in two unlined lagoons. In the middle 1970s the State Regulatory Agency claimed that the lagoons were the source of contamination of local surface and groundwater. During the late 1970s an exhaustive remedial investigation found additional sources of contamination at the site. Pathways of migration were primarily groundwater and surface water sediments. In the early 1980s a remedial action plan was implemented which included: removal of sludge from the two lagoons, removal of contaminated soil from the site and drainage ways, regrading, revegetation and stabilization of all soils on the site and installation of a groundwater collection and treatment system.

In the fall of 1985 the company was called to an administrative conference by the State Regulatory Agency and U.S. EPA. The company was informed that the previous remedial investigations and plans did not meet all present requirements. The agencies indicated that the company must review all the previously collected data and complete a new feasibility study.

INTRODUCTION

A chemical manufacturing facility began operation in the late 1950s manufacturing specialty chemicals for private and industrial use. In the course of operations, chemical compounds in various forms were transported to and from the site. The site cov-



General Site Plan

ers approximately 30 acres and consists of buildings, warehouses, storage areas and open land (Fig. 1). Since operations began, various methods have been utilized for handling wastes at this site. Waste handling and disposal practices conformed to standard practices at that time.

SITE SETTING

The topography of the site slopes gently to the southwest. Surface drainage on-site is diverted to a ditch which runs along the western property line. Several springs are located in the vicinity of the site. Of particular interest is a major spring, located approximately one-half mile south of the site, which feeds a stream that is used for trout fishing. The site is underlain by carbonate rocks which dip to the southeast with an approximate northeast-southwest trend. Several area thrust faults cross normal to the rock formations. Extending from the site to the major spring to the south is either a trace of a fault or a formation contact.

The bedrock contains abundant solution openings both above and below the water table. These openings are responsible for conduit systems allowing groundwater to move from the site in a direction parallel to the surface trend of the rock layers. Groundwater recharge is primarily through infiltration of surface waters entering residual soils and surface solution openings near the site. Groundwater flows from the eastern portion of the site to the west. At the approximate location of the thrust fault, the water table drops approximately 60 ft and flows southward to the spring.

PAST WASTE DISPOSAL PRACTICES

Chemical production began in the late 1950s. In the early 1960s, the company was notified of a chemical odor in the spring downgradient from the facility. In 1962, as part of its remedial action, the company constructed a concrete lagoon to serve as settling basin for wastewater generated on the site. In 1963 facilities were constructed to contain spills at the plant. In 1965 the company designed and began operation of the spray irrigation system on the plant site. Chemical wastes were directed to the concrete lagoon where the wastes were neutralized by lime addition. Wastewater in the concrete lagoon was then sprayed on the open grassed areas on the company's property.

REMEDIATION-1972

In 1972 the State Regulatory Agency required that the company solidify all the sludge in the concrete lagoon. The company entered into an agreement with the state and proceeded to solidify all materials under the direction of the State Regulatory Agency. These materials were placed in earthen impoundments (lagoons) (Fig. 1), backfilled and graded. In addition, a separate asphalt impoundment was removed and all other wastes were sent off-site for disposal. These lagoons were excavated into the underlying soils to a depth of 8 to 10 ft. The berm was built around the lagoons, and the solidified materials were placed in the unlined lagoons. The company complied with all aspects of the Regulatory Order by the end of 1972. A letter approving the remediation and releasing the company from liability was issued by the State Attorney General's office.

REMEDIATION-1984

In the middle of the 1970s, the State Regulatory Agency claimed that the two lagoons were leaking and were sources of contamination in water which was discharging into the local stream from the spring south of the plant. The State Regulatory Agency issued an Administrative Order in 1977 requiring the chemical company to prepare and submit a plan for the identification, collection and disposal of any solid wastes and soils on the company's property which contain specific chemicals or other substances deleterious to plant life, aquatic life, animal life and man. Solid wastes included but were not limited to the solidified material in the lagoons. Following the 1977 Administrative Order, several sampling programs were completed on the site, in nearby private domestic wells, in the spring and in the nearby stream. On-site sampling included the collection of soil samples from the surface to varying depths throughout the site, and water and sediment samples from the freshwater ditch. In addition, wells were drilled throughout the site (Fig. 2) to define the groundwater flow and groundwater quality. On the basis of this remedial investigation (RI), the sources of contamination were defined on the site and the pathways of migration from the site were evaluated.



Monitoring Well Location Map

Results of the chemical analyses from the program are subject to question because standard procedures for some chemicals had not been developed prior to 1981. The chemical company employed an outside contractor to develop acceptable procedures for the analysis of these chemicals. Through sophisticated methods, it was possible to detect and quantify chemical compounds down to the low parts per billion level. This detection limit was 1 to 2 orders of magnitude lower than had been possible in the early 1970s. Improvement in analytical techniques has introduced the problem of the "diminishing zero" in chemical analyses. This problem, which continues today, means that detection limits decrease by at least one order of magnitude every 3 to 5 yr. Therefore, a site found to be clean in the early 1970s is determined to be "dirty" in the 1980s because it has chemical com-

pounds present at levels in the range of parts per trillion. The presence of chemical compounds at any level can concern the public, trigger action by the Regulatory Agencies and subject a company to a repeat of environmental studies completed earlier.

As a result of the chemical data obtained in the late 1970s, the Administrative Order was amended in 1981. During 1981, the company complied with the Administrative Order and removed all the soils from a former drum holding area. Excavations were backfilled with clay, regraded and vegetated. The freshwater ditch was cleaned with a front end loader in the area of the lagoons, and a "supersucker" vacuum truck and hand excavation were used to clean the ditch. Contaminated materials were transported to a secure landfill. The freshwater ditch was brought back to original grade with clean clay fill.

Materials were removed from the two lagoons in the fall of 1982. All the solidified materials plus additional soil were removed from the bottom and sides of the excavated areas and transported to a secure landfill. Closure plans for the areas of solidified material were approved by the Regulatory Agency, and closure was completed with a clay cap in early 1984.

Recognition that groundwater had been adversely affected and was negatively impacting the spring resulted in the development of a groundwater collection and treatment system. Groundwater initially was pumped from wells adjacent to and downgradient from the facility. These wells had the highest concentrations of chemical contaminants. In the treatment system, water is pumped through a countercurrent air stripper and carbon adsorption system. Final discharge is to the surface drainage ditch on the property. A monitoring program was implemented in 1982 which consisted of measurements of groundwater elevation, groundwater quality and influent to and effluent from the water treatment system. Monitoring data have been compiled and monthly reports have been submitted to the Regulatory Agency.

REMEDIAL INVESTIGATION-1986

In the fall of 1985, the company was called to an Administrative Conference by the State Regulatory Agency and the U.S. EPA. The call came as a surprise to the company because there had been little indication of dissatisfaction with the remediation that had resulted in the removal of surface sources of contamination and the installation of a groundwater collection and treatment system. Groundwater quality had improved as shown by a general decrease in contaminant concentrations with time. The company believed that it was conforming to all necessary permit requirements and was effectively remediating the groundwater pollution.

At the Administrative Conference, the company was informed that the previous RI/FS work did not meet all the present RI/FS requirements. (Much of the work was done previous to the passing of CERCLA and reauthorization of RCRA.) At the request of the State Agency and the U.S. EPA, a new work plan for an RI/FS had to be developed.

Development of the work plan required review of previously collected data, some of which went back over a decade. Data were reviewed from the files of the consulting engineering and geotechnical firm (SMC Martin), district and central offices of the State Regulatory Agency and the regional office of the U.S. EPA. It immediately became clear why it is necessary for a consulting firm to retain records long after a job is completed. To quote the great American philosopher Yogi Berra, "it ain't over 'til it's over." Data must be reviewed in the light of present information and technical skills. Because of this, we found it extremely valuable to work with much of the original data and work sheets. In addition, review of data previously accumulated by regulatory agencies in their files was found to be time-consuming but valuable. Available internal agency memoranda helped focus on the critical issues to be addressed in the work plan. Agency cooperation is an important element in this review process. As a general rule, no one file was complete; the review of all files was required to obtain a complete data base.

This situation was especially true in the review of chemical data where sampling, collection methods and analytical techniques have made major advances in the last decade. We find that the level of detection for many of the analyses is now at parts per trillion, where a decade ago it was at parts per million. Thus, in reviewing old chemical data, one must be aware of the detection limits.

The review of the regulatory data files also helps develop an understanding of the changes in regulatory philosophy with time and the confidence of the regulatory agency in its data base. This understanding is critical for our case study because of the concern about the acceptability of previous chemical results.

A work plan for a "focused" remedial investigation and feasibility study has been developed. These "focused" efforts are directed toward site specific control features and data gaps particularly directed at the groundwater flow regime. The feasibility study also will be focused toward defining the effectiveness of the present remedial activities in meeting the State Regulatory Agency orders. If necessary to meet agency goals, supplemental remediation will be identified, evaluated, selected, designed and implemented at the site. All these RI/FS activities will be completed in a manner consistent with today's requirements and SMC Martin's perception of what may be reasonably expected in the future. Only the future will tell whether this site will be "revisited again."

CONCLUSIONS

Long-term efforts by a chemical producer to define and remediate contamination at a site have met with the State Regulatory Agency approval. However, this approval is no assurance that present or future state and federal agency regulations will not require further investigations and remediation at a site. As analytical techniques have become more sophisticated, it has become possible to detect compounds in ever smaller quantities at any and all sites. This increasing sophistication in analysis leads to the "diminishing zero" problem where the next generation of analytical techniques changes "not detected" levels into "quantifiable" levels, and materials which were absent suddenly appear on sites.

Because "focused" studies (revisits to a site) may be required in the future, it is important that all data, records and reports be carefully and completely maintained by the company, its consultants and other parties. These data must be maintained in such a format that they can be evaluated by persons not involved in the original studies and in the light of advances in scientific knowledge. They also must be maintained with the realization that it may be necessary to provide data to regulatory agencies.

Investigation and Remediation of A Pond Contaminated by Diesel Fuel

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ABSTRACT

Several diesel fuel spills occurred at a truckstop in Ohio, and significant amounts of fuel drained into a pond located 900 ft downstream. The pond became anaerobic and could not support aquatic life. On two occasions, the landowner burned large accumulations of fuel from the surface of the pond. In addition, areas of biologic stress were evident along the drainage path to the pond. In an agreement with the State of Ohio, an environmental investigation was initiated to evaluate the magnitude and extent of the contamination.

The investigation included hand-augered soil borings, chemical analyses of soil and sediment samples collected from the area downstream of the truckstop and a biological assessment. Based on the results of these studies and the preferences of both the client and the landowner, the contaminated soil was excavated and the pond was closed. A total of 7500 yd³ of fuel-contaminated soil was removed from the site to an approved landfill.

During the excavation, the pond became filled with uncontaminated sediment from the pond bottom. This sediment could best be characterized as an organic muck having a water content as high as 88% by weight. The pond was closed using geotextile fabric to stabilize and solidify this muck. This action saved approximately \$300,000 in comparison to the projected costs for total excavation and backfill.

INTRODUCTION

This paper presents the results of an environmental investigation and the remedial actions taken at a full service truckstop located in Ohio. Over the years, several diesel fuel spills occurred resulting in significant amounts of fuel draining into a pond located 900 ft downstream of the truckstop (Fig. 1). On two occasions, the accumulation of diesel fuel was burned off the pond. The flow path of the spills from the truckstop to the pond was marked by areas of biologic stress, and the pond became incapable of supporting fish and other aquatic species of life normally present in similar ponds.

In an agreement with the State of Ohio, the management of the truckstop initiated an investigation to assess the physical condition of the site, to assess the environmental impact of the diesel fuel spills and to develop any necessary remedial actions. The investigation included an assessment of the soils and surface water in the impacted area, as well as a biological assessment.

SITE DESCRIPTION

Topography in the area ranges from flat to gently rolling terrain. Surface drainage flows toward the west into the Mill Creek drainage.system. A large area south and west of the truckstop had been strip mined for coal and was covered by deposits of strip mine spoil. The pond was constructed in this strip spoil, approximately 900 ft west of the truckstop. Surface water from the truckstop drains into this pond.

Immediately downslope from the truckstop is a wide meadow surrounded by scrub forest. The forest closes in around a defined stream about halfway to the pond. Between this point and the truckstop, the drainage was poorly defined, migrating laterally across the meadow. The diesel spills covered an area from approximately 50 to 70 ft wide as runoff drained toward the pond. In this area, significant stress to the vegetation was observed throughout the meadow; barren areas were covered by black mucky soils, yellowing shrubs and dead trees. Further downstream, the channel became well-defined and areas of biological stress were confined to the immediate vicinity of the channel.

The pond was constructed by the landowner for recreational purposes. It was reported that the pond was originally about 20 ft deep. At the time of the investigation, the pond measured approximately 120 ft by 310 ft, and averaged 8 to 10 ft deep. Discharge from the pond flows toward the west through about 200 ft of established woods before reaching a cultivated area where the stream eventually enters a tributary to Mill Creek.

ENVIRONMENTAL SAMPLING PROGRAM

A two-phase sampling program was initiated on Oct. 2, 1984, to obtain soil and pond sediment samples for chemical analysis. The objective of the sampling program was to assess the degree of



Figure 1 Site Map of Study/Cleanup Area

diesel fuel contamination and its areal extent downstream of the truckstop. A total of 127 soil samples was collected from 63 stations located downstream of the truckstop and analyzed for diesel fuel content (Fig. 2).



Figure 2 Site Map Showing Sampling Locations 1'' = 100'

During Phase I of the investigation, a total of 45 samples was collected from 30 sampling stations located along the drainage path between the truckstop and the pond. At each station, soil samples were collected at approximately 1-ft vertical intervals. The sample and depths are listed in Table 1.

Table 1
Diesel Fuel Analysis of Soil & Sediment Samples
Truckstop Environmental Sampling Study, Phase I Sampling

STATION ID	LOCATION	SAMPLE DEPTH	DIESEL PUEL CONC mg/kg	PIRLD DH	COND.
	000			76	1 100
B	1+00			7.7	1,100
č	1+20	0-6*	4.600		.,
č	1+20	12-17*	14,500		
ċ	1+20	18-27"	1,790		
D	1+80	0-6*	1,780		
D	1.60	12-17"	100		
D	1+80	24-30"	+100		
E1	2+00	0-6*	4,780	.0	1,050
21	2+00	12-10"	7,880		
E2	2+00	0-4*	609		
22	2+00	12-18-	4,720		
P1	1.00	0-4"	8,020		1,050
	3+00	12-10-	640		
	3+00	24-26-	.100		
82	1-00	12-14"	1100		
	3.00	20-24*	(100		
6	1.75	0-4*	40.300		
č	1.75	12-16*	1. 10		
Ğ	3+75	24-28*	+100		
н•	4+00			7.8	1.000
I •	5+00			7.5	1.000
J	5+70	0-4"	150		
K.+	6+00			.0	1,050
L	7+00	0-6*	240	7.7	1,200
L	7+00	12-10"	•100		
м	7+50	0-6"	+100		
м	7+50	12-18*	190		
н•	8+00			6.8	2,150
0	8+15	0-6-	1,520		
0	8+15	12-10	100		
0	8+15	24-30-	1,090		
	9+00	0-6-	.100	1.1	2,500
	Bood Edge Al	12-10	1 160		
X	Pond Edge #1	12 18	1,300		
¥.	Pond Edge #5	0-6"	4100		
P	Pond Edge 45	9-14	(100		
s	Pond Edge 12	0-1*	(100		
s	Pond Edge #2	10-13*	100		
Ť	Pond Edge #1	0-6	4.630	6 6	1 200
Ť	Pond Edge #3	10-15*	100	•.•	5,200
Ű	Pond Edge 14	0-6"	550	7.4	1.200
U	Pond Edge 14	9-14*	+100		
v	Pond Trib.	-		7.5	2,400
W	Discharge 1+00	0-6"	2,350	7.4	2,200
x	Discharge 1+60A	0-6*	3,270	7.3	2,200
Y	Discharge 1+60B	0-6"	+100		-
21	Pond Sed S	Bottom @ 8'	+100	7.5	1,200
22	Pond Sed C	Bottom @ 7.3'	(100	7.6	1,200
Z]	Fond Sed N	Bottom @ 5'	(100	7.1	1,700

*Not shown on map.

Soil samples were collected from two depths at each of five stations (Q through U) along the edge of the pond. These are shown on Fig. 2. Additional soil samples were collected along the discharge stream from the pond (Stations W, X and Y).

Three bottom samples of pond sediment were collected for analysis. These samples were obtained using an inflatable raft and a scoop to dredge sediment from the pond bottom. The locations of these samples are shown on Fig. 1 as Z1, Z2 and Z3. The depths ranged from 5 to 8 ft as shown in Table 1.

During Phase II, an additional 82 soil samples were collected to further define the extent of contamination. The samples were collected from 35 stations located along the drainage course between the truckstop and an area downstream of the pond. Twentythree sampling stations were established along the drainage path and are shown as stations AA through FE in Fig. 2. Three additional stations were established around the edge of the pond and are labeled as stations PA through PC in Fig. 2. Ten more stations were established downstream of the pond's discharge point. Only two of these stations (GA and GB) are shown on the map in Fig. 1, the others (GC-GJ) are located off the map. The sample stations, locations, depths and analytical results are presented in Table 2.

Table 2 Diesel Fuel Analysis of Soil & Sediment Samples Truckstop Environmental Sampling Study, Phase II Sampling

STATIC			OTPSPI. PURI. PIRID	COND
ID	LOCATION	DEPTH	CONC mg/kg pH	anhos
**	1.00, 40' n	0-2'	20	
	1 00 201 1	2-4.	10	
A.0	1+00, 20° M	2-41	10	
Ň	1+00. 20' 5	0-2	4800	
BA	2+00. 40' N	0-2'	+10	
B.D	2+00, 20' M	0-2.	30	
88		2-41	•10	
BC	2+00, 20° S	0-1	240	
BC BC	2 00 401 6	1-1.5	•10	
80	2.00 40' 5	1-2.	.10	
CĂ	3+00, 40'N	0-2.	10	
CB	3+00, 50' N	0-2'	40	
cc	3+00, 30' W	0-2'	840	
CD	3+00, 20' S	0-1'	60	
CD		1-2'	60	
CE	3+00, 40' \$	0-1.	60	
DA	3+70, 40' W	0-21	10	
DB	3470, 20 .	1-2'	170	
EA	4+50, 80' N	0-2'	•10	
88	4+50, 50' W	0-2'	10	
BC	4+50, 30' N	0-2 .	·10	
ED	4+50, 30' S	0-1'	50	
8D		1-2'	60	
PA	5+50, 80' N	0-2'	-10	
r B	5+50, 30° M	0-21	20	
20	5+50, 30' 5	0-1	460	
		1-2'	90	
2 E	5+50, 50' S	05'	170	
PA	Pond Side	0-1'	<10	
PA		1-2'	•10	
28	Pond Side	0-1	•10	
- PP	Bood Marsh	1-2	•10	
PC	FORG HEIGH	1-2'	+10	
ĜĂ	Pond 1+50', Stream	0-1.	10	
GB	Pond 1+50, 10' S	0-1'	•10	
*GC	Pond 2+00, 40' N	0-1'	•10	
		1-2'	•10	
۰ĢD	Pond 2+00, 20' N	0-1.	410	
108	Pond 2.00 201 6	1-2	110	
	1000, 10 5	1-2'	+10	
*G#	Pond 2+00, 40' S	0-1'	•10	
		1-2'	10	
+GG	Road 2+00, 40' N	0-1*	•10	
		1-2'	•10	
•GH	Road 2+00, 20' N	0-1.	+10	
*67	Road 2:00 201 5	1-2'	•10	
.01	NGEU 2+00, 20° 5	1-21	10	
•GJ	Road 2+00. 40' S	0-1'	+10	
		1-21	+10	
		-		

*Not shown on map.

BIOLOGICAL ASSESSMENT

The objective of the biologic site inspection was to determine the effect of discharged diesel fuel on the biota of the areas. As previously described, diesel fuel spills from the truckstop followed a natural drainage path to the small man-made pond (Fig. 1).

The diesel fuel concentrations found in the soil samples collected during the environmental sampling program were significantly high and can be expected to adversely impact vegetation, benthic organisms and pond fauna. The effect of diesel fuel on vegetation is usually first expressed in the yellowing of leafy material; eventually the entire plant dies. Yellowing and death of larger trees generally indicates a deep penetration of the contamination.

Drainage Ditch

Significant stress to the vegetation was observed in the area between the truckstop and the pond. The area directly downslope from the truckstop was void of healthy vegetation, and much of the area was covered with a black, mucky soil. In some places, free oil was found on the surface. A winding area of similar character continued through the meadow vegetation to three similarly void areas farther down the drainage path. These areas were measured and found to be approximately 600, 200 and 140 ft² respectively. Within or alongside these areas, more than 20 trees were dead. Each had a diameter at breast height (DBH) of 1 to 3 in.

Benthic Organisms

The stream course was searched for benthic organisms on two different occasions, but none were found. Rock samples were taken back to the laboratory, picked and examined microscopically. No benthic organisms were found. Glucose solution was used to float out any organisms, but again, to no avail. The toxicity of diesel fuel components to benthic populations appears to be responsible for the lack of benthic organisms along the drainage path to the pond.

Pond

Dissolved oxygen levels were measured at four locations around the pond. The average level for each location was as follows:

Sampling Site	Dissolved Oxygen (Concentration mg/l)	i
---------------	---------------------------------------	---

a) Stream leaving pond	3.1
b) West side of pond	1.6
c) South side of pond	1.8
d) East side of pond	1.3

The measurements were taken at 6:30 p.m. on Oct. 2, 1984; all oxygen concentrations were well below the levels required to sustain most higher forms of aquatic life.

Samples of the pond sediment were taken to the laboratory and examined microscopically. No insects or insect exuviae were discovered. One damselfly shell was found alongside the pond, and a bullfrog tadpole (*Rana catesbiana*) was collected from the water. No signs of life were observed. Samples of the pond water underneath the oil layer were examined microscopically. The green algae Spyrogyra sp. was found mixed with tiny droplets of oil emulsified in the water.

RESULTS

Results of the environmental sampling program and laboratory analyses indicate that diesel fuel was present in the soils of the study area at concentrations of up to 40,300 mg/kg (Table 1). The extent of contamination as a result of the diesel spills at the facility was not limited to the drainage area just below the facility, but extended to the pond and beyond it (Fig. 3).



Site Map Showing Diesel Fuel Contamination Levels 1'' = 100'

Eighteen of 123 soil samples had diesel fuel concentrations in excess of 1,000 mg/kg. Most of the higher concentrations were found in samples along the drainage path between the truckstop and the pond. Only three of the surface samples (0 to 6 in. deep) taken from the edge of the pond had detectable levels of diesel fuel. However, none of the samples from the bottom of the pond contained detectable levels of diesel fuel. Relatively high concentrations of diesel fuel were detected along the discharge stream from the pond.

Diesel fuel was detected in 36 of the soil samples along the drainage path. Of these samples, 7 had concentrations in excess of 1,000 mg/kg. Most of these higher values were located in areas where the drainage was poorly defined, and the fuel had accumulated in depressions away from the primary drainage channel. At the stations where deeper samples were collected, most of the samples showed a decrease in diesel concentration with depth, except at stations C, E and O. These areas showed an increase in the concentrations with depth. Results of the sampling and chemical analyses indicate that the diesel contamination was limited to a depth of less than 2 ft.

Based on the soil sampling around the pond, we concluded that the contamination was concentrated in the shallow surficial deposits of muck and partially decayed plant matter. Little diesel fuel was detected in the clayey soils beneath the muck. Samples of the sediment from the bottom of the pond at locations Z1, Z2 and Z3 did not contain detectable levels of diesel fuel. In the area of the pond and associated marsh, persistent contamination appeared to have occurred only in the shallow surficial muck deposits around the edge of the pond and the swamps.

The analyses of the two soil samples collected downstream of the pond in Phase I indicate that significant contamination of soil extends beyond the pond. Concentrations of over 2,000 mg/ kg of diesel fuel were detected in the soil. Phase II showed that this contamination did not extend 200 ft downstream from the pond.

Significant biological distress was noted in the study area as a result of the diesel spills. In large areas, the establishment of vegetative ground cover was retarded. Some areas contained established trees and shrubs which died as a result of diesel contamination. A biological survey of the stream indicated an almost total absence of aquatic life in this area.

Dissolved oxygen levels in the pond are below the levels required to sustain most common aquatic life. No aquatic organisms were found in the pond except for a few tadpoles. The pond had euxinic bottom conditions where the water was so stagnant that organic matter reaching the bottom of the pond was shielded from oxygen and decay.

REMEDIAL ACTION

Several remedial action alternatives for dealing with the diesel fuel contamination at the site were considered and assessed. The alternatives were: (1) no action, (2) total removal, (3) in situ treatment and (4) land farming. Based on the potential effectiveness of each option and the estimated cost of each method, land farming was recommended as the most suitable remedial action. However, the preferences of both the client and the landowner led to the total excavation and removal of the contaminated soil and, subsequently, the closure of the pond.

Originally, excavation of the contaminated soil (>100 mg/kg) was to have been accomplished in three phases. During the first phase, the pond was to have been drained to allow the contaminated soil along the edge of the pond to dewater. This step would have allowed the moisture content of the contaminated sediment to decrease to a level where soil solidification would not have been necessary. In the second phase, the contaminated soil in the drainage ditch was to have been excavated to an approximate depth of 2 ft and regraded. During the third phase, the pond was to have been completely drained and the contaminated soil excavated. The proposed excavation boundaries are shown in Fig. 4.

This process did not occur as planned because of conditions imposed by the geology of the site, the Ohio EPA (OEPA) and the landowner. The latter requested that the pond be filled in, which resulted in the fourth phase, pond closure.

Draining the Pond

Initially, an attempt was made to drain the pond by lowering the elevation of the outlet. When the outlet was excavated, flow from the pond was so great that it disturbed the organic sediment on the bottom of the pond, and some of this material moved downstream. Although the organic sediment previously had been found to contain ≤ 100 mg/kg diesel fuel and was considered harmless, the landowner and the OEPA wanted the flow stopped.

As a result, a second attempt to drain the pond began. Two high capacity pumps were used. The intake hoses were suspended from a floating barrel to prevent the sediment and organic muck in the bottom of the pond from being drawn into the pumps and subsequently discharged. Personnel were stationed by the outlets to monitor discharge and ensure that no organic sediments were being discharged to the stream. When sediments were detected, the locations of the inlet hoses were adjusted until the levels were such that the pumps had to be cut off. In addition, water flowing into the pond was rerouted to limit the recharge to the pond. Once the pond was drained as much as possible, the elevation of the outlet was lowered to prevent the water from rising to its original elevation.



Site Map Showing the Proposed Limits of Cleanup 1'' = 100'



Figure 5 Site Map, Boundaries of Cleanup 1'' = 100'

Excavation of the Drainage Area

In the second phase, contaminated soil in the drainage ditch was excavated and hauled to a landfill. Along the drainage path, soils were excavated to an average depth of 3 ft and decreasing to a depth of 1 ft as the excavation boundaries were reached. A map showing the actual areal extent of excavation is shown in Fig. 5. At several points along the stream channel, excavation went much deeper due to the excessive levels of contamination found. Approximately 1800 yd³ of fuel-contaminated soil were excavated from the drainage course and hauled to the landfill. Upon completion of the excavation, the area was regraded, fertilized and seeded.

Excavation Around the Pond

Excavation of the contaminated soil around the pond did not proceed as originally planned. The landowner requested that the pond be filled in and that the trees located around the pond be allowed to remain standing. As a result, the excavation had to be accomplished from inside the pond area where soil conditions would not support the weight of the construction equipment.

To accommodate this process, an earthen ramp and work pad were built at the southern end of the pond. From the work pad, a backhoe was used to excavate the contaminated soil, which then was replaced with fresh soil brought in from a local construction site. The soil was used to extend the work pad area and to construct a haul road for the trucks moving in and out of the site along the edge of the pond. As the fresh dirt was hauled in and dumped along the edge of the pond, sediment at the bottom of the pond was displaced toward the center. When the mouth of the outlet stream was reached, the pond was effectively divided in two by building a coffer dam/road from west to east across the pond, and the accidental discharge of sediments into the outlet stream was prevented.

Excavation then continued until the contaminated soil around the pond was removed. During construction of the access road, the original area of the pond was reduced by approximately 40%, free water was discharged to an adjacent stream and the organic sediment in the bottom of the pond was retained and collected in the center of the pond. Approximately 5700 yd³ of fuel-contaminated soil were excavated from around the pond and taken to a landfill for disposal.

Pond Closure

As a result of the procedures used to excavate the contaminated soil, two ponds containing displaced sediment from the bottom of the pond were created. The north pond measured 100 by 100 ft with an average depth of approximately 15 ft, while the south pond measured 83 by 180 ft with an average depth of approximately 25 ft. Each pond was filled with a sediment best described as muck. The material was not contaminated, had a high flashpoint (180 °F) and was saturated, containing as much as 88% water by weight. Because of its high water content, the muck could not be removed to a landfill or buried in situ without treatment.

Treatment of the muck would have required solidification using kiln dust, fly ash or other cementaceous materials. Based on the available data, the estimated cost of solidifying the muck would have been in excess of \$250,000. During this process, the volume of the muck would have increased a minimum of 100%, necessitating removal of some of this material to a landfill at an estimated cost of \$200,000. The area then would have to be regraded and capped with clean soil. It is estimated that the total cost of this project would have exceeded \$550,000. By using geotextile fabrics to stabilize and solidify the muck, the cost of closing the pond was \$198,000, a savings of over \$300,000 over the removal cost.

The basic concept of mechanical stabilization is to use the natural weight of a cover soil to consolidate and dewater the sediment. A layer of geotextile fabric is placed on top of the sediment to provide support, a thin layer of sand is spread across the fabric to provide a drainage layer and then cover soil is spread on top (Fig. 6).



Detail Section of Pond and Anchor Trench



Figure 7 Stages of Geotextile Fabric Installation

Prior to the installation of the fabric, the site had to be properly prepared. The muck in the north pond was transferred to the south pond (Fig. 5). During the excavation of the contaminated soil, streams coming into the pond were diverted. A ditch to carry these streams across the area was designed specifically to act as a catchment basin for the initial discharge of water coming from the south pond during stabilization. This ditch was constructed in the area of the north pond. If an emergency had occurred, the ditch could have been used to contain any organic sediment as it left the site.

Next, the road around the site was cut to the same elevation as the muck and graded to match the surrounding topography. Finally, two trenches were constructed on the south and west ends of the site to anchor the fabric (Fig. 6). These sides were chosen to prevent a sediment spill from discharging to the stream below the pond.

The fabric selected for the project was manufactured by Carthage Mills and measured 150 by 260 ft. The fabric had a burst strength of 585 lb/in.². The fabric was stretched over the pond and the edges were buried in the anchor trenches.

Once the fabric was in place, soil was end-dumped along the west, south and east edges of the fabric (Fig. 7A) and spread to an approximate depth of 3 ft using a small, wide-track dozer with 2.6 $lb/in.^2$ contact pressure. On the northern end of the pond, 1 ft of sand was positioned on top of the fabric, and then 2 ft of soil were emplaced on top of that. This process kept the fabric from slipping and provided a drainage pathway for water being extruded from the muck.

A layer of sand then was placed over the rest of the fabric to provide a drainage path for the water being pressed out of the sediment (Fig. 7b). The sand was placed in 5-ft strips starting along the northeast side of the pond and working around the edge of the haul road until the entire pond was covered. This process prevented any sediment spillage due to uneven loading and provided a solid working surface for the final soil placement and grading.

Originally the sand layer was designed to be 2-ft thick; however, because of the inexperience of the operator with this type of operation and the large amounts of water being released from the sediment, the sand often reached thicknesses of 4 ft. Finally, a 2-ft layer of dirt was placed over the top of the sand to add weight and cap the pond (Fig. 7c).

CONCLUSIONS

During the course of the project 7500 yd³ of fuel-contaminated soil were excavated from the site and removed to an approved landfill. Over 12,000 yd³ of clean fill were used at the site to replace the contaminated soil and construct the haul roads. By using geotextile fabrics to stabilize and solidify the organic sediment, a cost savings of approximately \$300,000 was realized for closure of the pond.

Innovative and Cost-Saving Approaches to Remedial Investigation and Cleanup of a Complex PCB-Contaminated Site

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ABSTRACT

A combined remedial investigation and feasibility study was performed on a complex PCB-contaminated passenger railroad terminal. A statistically based iterative sampling and analysis scheme and several mathematical models developed for migration of PCBs in various media together will save from 30 to 60% of the time and cost that would otherwise be required for the investigation and cleanup. Several processes were examined for waste minimization through physical/chemical separation of approximately 1,000 tons of PCB-contaminated waste from 3,000 tons of insignificantly PCB-contaminated waste.

Evaluations of PCB contamination were made for over 15 types of substrates, including soil, rock, wood, asphalt, concrete, steel, glass and roofing paper, among others. A screening technique, thin-layer chromatography, was tested for use in providing quick determinations of highly PCB-contaminated samples, but was adversely affected by masking organic compounds. As cleanup proceeds, an on-site mobile laboratory will provide critical quick sample turnaround.

INTRODUCTION

In the spring of 1985, the owner of this complex passenger railroad terminal initiated a remedial investigation of PCB contamination. The majority of the on-site PCB contamination resulted from the use over several decades of electric-powered railroad cars with PCB-containing transformers. The PCB contamination generally was viewed as historic because it primarily occurred prior to the implementation of the Toxic Substances Control Act of 1979. Therefore, the law allowed time to assess the best approach to clean up the site.

The terminal consists of an elevated, 1,100-ft long viaduct which provided access by trains, a 150,000-ft² (about 4 acres) terminal shed which provided cover to passengers and an interstitial space which separates the floor of the shed from a public facility below.

The site posed many technical and logistical problems because of its size, uniqueness and urban location. WAPORA was selected to perform a remedial investigation and ultimately oversee cleanup of the entire site. From the outset, an iterative approach to the remedial investigation was utilized in order to minimize costly and unnecessary investigative efforts. For example, the trackbed sediments in the terminal shed were quickly tagged for cleanup, since a limited number of samples all showed substantial PCB concentrations and it was known that PCBs had a strong affinity for the sediments. On the matter of air contamination, early results showed non-detectable PCB concentrations. As with the trackbed sediments, a knowledge of the chemical nature of PCBs was used in combination with early sampling results to minimize the need for a more intensive investigation. Air sampling was continued, but less comprehensively.

The following sections detail the innovative and cost-saving approaches taken during the remedial investigation and in the development of the cleanup plan for the viaduct, the terminal shed and the interstitial space.

VIADUCT

The viaduct provided an elevated structure for access to the terminal by passenger trains. The upper 3 to 4 ft of the viaduct generally consist of railroad ballast (granite rock), which varies from 1 to 3 in. in diameter, interspersed by sand, cinders and ashlike fine materials. The structure beneath the ballast and fines consists mostly of landfilled demolition materials. There is a concrete base underlying the ballast and fines over about one-third of the viaduct, which serves as an elevated support for rail overpasses.

Remedial Investigation

To perform the remedial investigation efficiently and to generate results which would be most useful in the development of the cleanup plan (i.e., serve as a feasibility study), several key objectives were identified at the outset:

- Determine if a statistically significant correlation exists between depth and PCB contamination
- Determine the extent and depth of PCB contamination
- Determine if a statistically significant correlation exists between sediment and ballast PCB contamination

Randomly selected samples of viaduct sediment were taken on a grid system at 50-ft intervals on the north/south axis and at 25-ft intervals on the east/west axis. Most samples were taken at 6- and 12-in. depths since the shallow layer was already considered contaminated. A statistically significant correlation was found for decreasing PCB concentrations in the sediment with increasing depth:

$$d = 0.5 \log \frac{Co}{Cd}$$
(1)

where:

- Co = sediment concentration of upper layer
- Cd = PCB sediment concentration at a depth d below the upper layer
- d = depth in ft

Simply put, the PCB concentration was found to decrease by approximately one order of magnitude for each 6-in. increase in depth. This correlation was consistent and reliable enough to be applied to remedial investigation results and eliminate the need for perhaps another 100% of the sample collection and analysis effort already performed. Identifying this correlation provided the groundwork to more easily determine the depth of ballast/ sediment removal needed. The viaduct was split into 16 areas, each having similar levels of PCB contamination. The correlation was used to create statistics for each area, thus providing a sound basis for a "semi-surgical" approach for removal.

The last major objective of the remedial investigation of the viaduct was to determine the correlation of PCB contamination in sediment versus adjacent ballast. Since sediment has a greater surface-area-to-volume ratio than ballast and the ballast is impenetrable to PCBs, the theory was that sediment-free ballast samples would have substantially lower PCB contamination levels than sediment samples from locations directly adjacent to them. The results showed that, in fact, the ballast PCB concentrations were significantly lower than those of the sediment. However, a fairly significant range of from 10 to over 100 existed for the ratio of the sediment PCB concentrations to the ballast PCB concentrations.

Feasibility Study

Analytical tests performed on the ballast showed that the PCB contamination was a surface phenomenon and that the ballast is impenetrable to PCBs (Table 1). In fact, the results showed that, for selected samples, the PCBs were readily extracted from the ballast in a solution of hexane within 15 to 60 min.

Table 1 Results of Ballast Rock Analysis for PCBs

location ⁸	Concentrations associated with beliest (pps)					Corresponding	Ratio of FCB	
	Depth (ft)	Sample 1.D. f	Removed after 15 min	Ramoved after 40 min. b	Ramoved after 16 hrs.	tentining ^c	concentration ^G (ppm)	contesinetion in soil versus bellast
200 8, 12 9	0.05	5116	_	_	1.1	(0.1	47	39
600 S. 22 E	0.05	5104	-	-	1.8	<0.1	210	117
700 8, 14 9	0.05	5121	-	-	0.74	<0.1	48	65
KO 1, 26 K	0.05	5006	-	-	53.0	<0.1	9300	175
100 H, 24 H	0.05	5111	-	-	1.00	(0,1)	73	73
100 F. 13 F	1.00	5110	-	-	0.35	<0.1	34	109
100 H, 42 W	0.03	5008	3.8	0.25	-	<0.1	290	72
300 H. 13 W	0.05	5057	0.75	(0.1	-	<0.1	43	57
400 H. 10 W	0.05	5010	0.46	<0.1	-	(0.1	20	44

a. Distances in ft; N = north of shed mouth; E/W = distance east or west of centerline of track 1 in terminal shed.

b. Extraction of sample rock in hexane solvent.

c. Remaining ballast rocks were crushed and total extraction of remainder was analyzed.

d. PCB concentration in soil adjacent to ballast.

The results of the remedial investigation showed a wide range of ratios of sediment PCB concentration to ballast PCB concentration. This range was primarily the result of one major problem: clumps of oily sediment with strong cohesive properties were frequently fused with the ballast rock or formed wholly separate clumps which were difficult to distinguish or separate from the ballast. Therefore, several options were evaluated for converting the ballast to a non-regulated material which would not require disposal as a PCB-contaminated waste. These options included:

- Simple physical separation through screening
- Physical separation through vigorous vibration and screening
- Physical separation through tumbling enhanced by the addition of agitating attachments
- Enhanced physical separation followed by a detergent wash
- Enhanced physical separation followed by a solvent wash

The options involving chemical actions (washing) required authorization from the U.S. EPA to use PCB-contaminated materials in testing such techniques. Tests of simple screening separation of ballast and sediment, which required no authorization, showed that approximately 35% by weight of the finer material can be removed easily by simple screening and disposed of as a PCB-contaminated waste (Fig. 1). The remaining 65% contained less than 35% of the total original PCB contamination.

Enhanced screening alternatives include the use of vibratory grizzly screens (similar to foundry shake-out units) followed by shot blasting with recycling of shot. These are pre-developed technologies used by the foundry industry to separate molding sands from newly formed casts. Other physical separation alternatives include: (1) the use of a rotating, inclined cylindrical screen (trommel) enhanced by the addition of reusable agitating attachments in a flow-through operation, and (2) a batch operation using a cement-mixer type of device to agitate the ballast in unison with reusable agitating attachments.



Simple Screening Separation Technique

The detergent washing technique could only be followed by one of the previously discussed physical separation steps. The detergent washing can be performed on a batch or flow-through basis. It involves reclamation of the wastewater through diatomaceous earth filters and granular activated carbon columns.

It presently is anticipated that an on-site mobile laboratory will be used to provide quick turnaround analysis of PCB samples. This will be critical since materials which are assumed to be clean after separation will be stored until quality assurance samples demonstrate that fact.

TERMINAL SHED

The terminal shed is a structure nearly 4 acres in area with an arched, structural-steel-supported spanning roof. It is open at one end to allow trains to enter. The floor consists of alternating rows of dual trackbeds and elevated passenger walkways constructed of concrete and asphalt (Fig. 2).



Figure 2 Cross-Section of Trackbed and Passenger Walkways in Terminal Shed

Remedial Investigation

Three types of samples were taken and analyzed in an effort to delineate the extent of contamination of materials and surfaces within the shed and link areas of the terminal. First, wipe samples of vertical surfaces (including structural steel, glass and metal duct work) and floor surface were taken to identify the extent of surface contamination. Second, passenger walkway materials (mostly asphalt with some concrete) were sampled and analyzed to determine the extent of permeation of PCB materials into these surfaces. Third, the vertical and horizontal penetration of PCBs into wooden support structures within the trackbed was determined by taking samples of the 2-in. thick bed support planking between track rail supports and the 14-in. wide by 10-in. high rail support beams.

Scientists from the U.S. EPA were concerned before the remedial investigation that re-entrainment of PCB-contaminated particles may have occurred throughout the entire shed structure. Therefore, the objective of the remedial investigation was to determine the level of PCB contamination relative to the U.S. EPA high-contact surface PCB contamination action level of 10 $\mu g/100$ cm². A secondary objective of the remedial investigation was to test the hypothesis that the PCB contamination that was present would decrease rapidly as height above and distance from the trackbeds increased.

Thirty-four wipe samples were taken and analyzed. All results showed surface contamination levels to be less than the $10 \,\mu g/100$ cm² U.S. EPA action level, with most below 1 $\mu g/100$ cm². The



results also generally supported the hypothesis that PCB contamination decreased with height above the trackbeds.

The wearing course in the passenger walkways consists of asphalt and, occasionally, concrete (Fig. 2). A combination of wipe samples and substrate samples was used to evaluate the extent of PCB contamination in the walkways. In all, 10 substrate samples were taken in the walkways (Fig. 3). Several substrate samples were taken in pairs at the surface and at depth in order to evaluate the potential for downward PCB migration. The substrate sample results all supported the conclusion that PCB contamination, theoretically from tracking, was insignificant in the materials.

The trackbeds consist of 2-in. thick planking overlain by a heavy woven fabric and by deposits of dust and soil. The rails are supported by hardwood pads above hardwood rail support beams (Fig. 2). The trackbed deposits and heavy woven fabric were determined to be PCB-contaminated during a prior, less detailed study. The underlying 2-in. support planking, however, was found, surprisingly, to be insignificantly PCB-contaminated through several randomly selected (and worst-case selected) sampling efforts.

The hardwood pads, due to their small size and proximity to potential PCB sources, also were assumed to be PCB-contaminated.

The hardwood rail support beams posed the most challenging portion of the shed investigation. The beams' dimensions are 10 in. high by 14 in. wide by 50 ft long. In all, there are over 2 miles of total beam length. The size and total available length of the beams make the potential resale of non-contaminated portions quite attractive. An evaluation of their potential resale is under way. The hypothesis was made that PCB penetration into the beams was primarily from the top and secondarily from the sides, and decreases with increasing depth. Fifteen composite samples of wood at various depth intervals from the top and sides of several beams (including suspected worst-case beams) were taken. The following correlation of surface PCB contamination and concentrations at depth was determined:

$$Cs/Cd = (6.0 \times Dp) - 0.5$$
 (2)

where:

Cs = PCB concentration at the upper (or starting) depth

Cd = PCB concentration at the lower (or inner) depth

Dp = Depth interval between upper and lower depth in in.

Generally, the results of the investigation showed that the beams could be salvaged for potential reuse by planing 3 in. off the top layer and 2 in. from each side layer. This approach would involve two special areas of precaution. First, in removing the beams, extra care needs to be taken in handling, since they weigh approximately 3,000 lb each, are quite awkward (50 ft long) and there is little substantial building structure separating them from occupied spaces below. Second, the milling/planing of the beams will require collecting dust, eliminating exposure to workers/public and maintaining a relatively low-temperature blade. It was determined that formation of more hazardous byproducts (furans/dioxins) through saw blade temperature excursions was unlikely, since blade temperatures could be maintained below 500 °F.

INTERSTITIAL SPACE

The interstitial space is the air space between the floor of the train shed and a suspended ceiling (functioning as a roof) of the publicly utilized area below. The interstitial space is "criss-crossed" by built-up l-beams with heights varying depending on the portion of the shed floor that is supported by individual beams (Fig. 4). The floor of the interstitial space is also the ceiling

of the public area below; it is a wood structure covered by several layers of roofing material, including a sheet metal layer and varying layers of a thick, flexible roofing felt and a thick, rigid roofing felt. The number of total layers of felt tar paper can vary from one to four.



Figure 4 Three-Dimensional View of the Interstitial Space Structure and Support

Remedial Investigation

During the early stages of the remedial investigation, it was determined that pooled PCB-contaminated liquids existed on small portions of the floor of the interstitial space, caused by blocked-up drains at the ends of the troughs (Fig. 4). Since the area below was used by the public, the presence of PCBcontaminated liquids in these troughs was considered unacceptable and required immediate removal. Tests showed, however, that no substantial PCB contamination had seeped to areas involving direct contact by the public.

The remainder of the remedial investigation included determination of the extent of PCB contamination of the felt paper on the floor of the interstitial space and of the PCB-contaminated deposits and stains on the structural supporting I-beams. Holes left after rivets rusted out on the top edge of the I-beams were the main avenues for leaks of PCB-contaminated diesel fuels and sediment in rainwater to the interstitial space. Generally, for practical reasons, all portions of the floor which had oil stains were assumed to have PCB-contaminated deposits and two layers of PCB-contaminated felt paper beneath them. All I-beams with oily deposits and stains were marked during the remedial investigation for the eventual cleanup. The remedial investigation was hampered by extreme difficulty in access because of such obstacles as 1-ft high clearances, the need for continuous use of artificial lighting and the requirement that work be performed only at night.

CONCLUSION

Considerable time and financial savings (perhaps 50%) were realized by the property owner through the development of statistically significant mathematical models during the site investigation. Several of these models were developed further and enhanced by testing several separation techniques for PCB-contaminated rock and soil. It is anticipated that the property owner will save at least \$500,000 during the cleanup phase, depending on the disposal option chosen, due to the development of the separation technique.

The entire investigation has been conducted in a heavily populated/visible urban location. Protection of the public health, environment and site personnel has been managed without incident.

Installation of Monitoring Wells Into Wastes in the Love Canal

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ABSTRACT

Three 2-in. stainless steel long-term monitoring wells were installed into waste materials in the Love Canal to provide water level data along the length of the canal. This information, in conjunction with analyses of soil/waste samples and other water level data from previously installed instrumentation, allowed an assessment of the geohydrologic conditions within the canal, determination of the effectiveness of remedial measures previously undertaken and characterization of waste materials still present.

Drilling and installing the monitoring wells was completed using conventional hollow stem auger drilling and split-spoon sampling methods. Special site conditions, such as previously implemented remedial construction did, however, pose difficulties in making borings and installing monitoring wells within the canal. Some of these difficulties included the following:

- Penetration of a subsurface synthetic liner over a clay cap and repair of the synthetic liner after completion of the monitoring well to preserve liner integrity
- Management of potentially highly contaminated auger cuttings
- Protection of the contaminant-free ground surface at each boring location
- Decontamination of potentially highly contaminated drilling equipment and tools

To minimize impact to the environment and workers and to protect and maintain the integrity of existing remedial systems, the project engineer, in conjunction with state and Federal agencies and its subconsultants, developed and implemented some innovative but relatively inexpensive procedures and methods for the installation of the wells. Some of these methods included:

- Use of a high density polyethylene (HDPE) boot system for access through the canal cap and synthetic liner
- Use of stock tanks and conductor casing to manage auger cuttings
- Use of HDPE and plastic as a spill containment liner system beneath the drill rig
- Use of specially adapted decontamination procedures

INTRODUCTION

The purpose of this paper is to present a case study of one segment of an extensive and on-going study of the Love Canal and Love Canal Area. The paper does not detail the findings of the study; rather, it presents methods and procedures used to install monitoring wells into the Love Canal, a potentially highly contaminated subsurface environment.

As part of the Love Canal Long-Term Monitoring Program Implementation Project, the Jordan Company installed three monitoring wells in waste materials in the Love Canal at Niagara Falls, New York. The installations were performed in cooperation with and for the New York State Department of Environmental Conservation (NYSDEC) and the U.S. EPA.

The objectives of the canal wells, in conjunction with other instrumentation installed during the project, were to:

- Determine fluid levels within the former canal to be used in the evaluation of the effectiveness of a barrier drain and the effectiveness of the synthetic and clay cap in controlling fluid influx
- Provide information regarding the nature and integrity of geologic deposits immediately below the waste materials
- Provide samples of soils and wastes for analysis to allow characterization of these materials along the length of the canal

BACKGROUND

The Love Canal site is located near the Niagara River on the eastern limits of the City of Niagara Falls, New York (Fig. 1). The area consists of largely abandoned single and multi-family residential housing within the Love Canal Emergency Declaration Area. The canal is bounded by Frontier Avenue to the south, 96th Street to the west, 100th Street to the east and Colvin Boulevard to the north (Fig. 2). These boundaries enclose an area approximately 3,000 ft long and 600 ft wide.

Major remedial actions and construction carried out at the site to date have included:

- Installing a perimeter barrier drain around the former canal to control the potential for lateral contaminant migration away from the canal
- Building and operating a treatment plant to treat leachate collected by the barrier drain system
- Establishing a clay cap over the canal area
- Extending the 300-ft-wide cap constructed to the outer edges (furthest from the canal) of 97th and 99th Streets using a synthetic 40-mil-thick High Density Polyethylene (HDPE) membrane and a silty clay cover
- Installing a security fence

Presently, the cap on the canal creates a mound about 9 ft high along the center of the canal which slopes gently to the east and west edges. The boring and well locations (Fig. 2) were situated at the top of the canal cap along the approximate centerline of the canal. An interpretive cross-section (Fig. 3) depicts the generalized configuration of the canal, cap and barrier drain.

One aspect of the Long-Term Monitoring Program Implementation Project required Jordan and its subconsultants to devise methods to efficiently and safely install 2-in. diameter, stainless steel monitoring wells in the wastes in the canal. To date, three wells have been installed in the canal. The locations of the




Figure 3 Interpretive Cross-Section—Love Canal

borings and wells, the previously constructed remedial work, the potentially hazardous wastes deposited in the canal and the public's concerns about drilling through the wastes have all posed numerous problems to successful completion of the project.

It was recognized that new methods and procedures addressing these problems would have to be developed to successfully complete the project as proposed. Through a cooperative effort between NYSDEC, Jordan and its subconsultants, methods were devised to:

- Access each boring location with a conventional drilling rig without rutting or damaging the grass, topsoil and silty sand overlying the canal cap and the HDPE liner
- Penetrate the existing HDPE liner and clay caps in a controlled manner to preserve the integrity of the cap



Figure 2 Boring and Well Locations

- Safely conduct boring operations, collect continuous soil and/ or waste samples, and install monitoring wells within the waste materials in the canal
- Collect and manage cuttings generated from drilling activities
- Protect the clean ground surface at each well location from being contaminated by subsurface wastes brought to the surface by drilling operations
- Safely and efficiently transport and decontaminate drilling tools and equipment without dispersing contaminants

DRILLING EQUIPMENT AND PROCEDURES

A CME model 550 drill rig was used at the site to make the borings and install canal wells. A conventional drill rig of this size weighs approximately 32,000 lb and exerts approximately 3,200 lb of compressive force at each of ten wheels. To protect the canal cap and liner from stress and excessive compressive loading, the drill rig was mounted on the chassis of an all-terrain vehicle (ATV) equipped with low pressure, high flotation tires. The distribution characteristics of these tires allowed the ATV to easily access all canal boring locations without rutting or damaging the topsoil overlying the canal cap or the HDPE liner.

Hollow stem augers were selected over cased borings as the means for making the borings at each canal well location for the following reasons:

- Hollow stem augers were effectively and safely used to make borings through similar waste deposits at the Hyde Park Landfill in Niagara Falls, New York
- Hollow stem augers were used effectively to install other wells in proximity to the canal during Phase I work of the Long-Term Monitoring Program Implementation Project
- Drilling fluids are not needed, thus reducing the potential for a spill of contaminated liquid materials and decreasing the volume of fluids and soils which would have to be managed
- Hollow stem auger borings can be completed relatively quickly, thus, reducing the amount of time the borehole and associated cuttings are open to the atmosphere

The canal borings in which canal wells were installed were made with 4.25-in. I.D. continuous flight hollow stem augers. Two-foot-long split-spoon samples were collected continuously beginning approximately 4 ft below the existing ground surface and through the waste materials until the bottom of the canal excavation was encountered, which was evidenced by a transition from waste and fill materials to undisturbed soils.

The continuous, split-spoon samples provided information related to:

- Previous capping
- The nature of waste materials deposited in the canal.
- The elevation of the interface between the wastes and undisturbed soils
- The geologic characterization of undisturbed soils below the wastes

After undisturbed soils were encountered, an additional soil sample was obtained using a 2-ft long, split-spoon sampler to confirm the presence of undisturbed soils. If the sample confirmed the presence of undisturbed soils, the boring was terminated.

Monitoring wells were installed in three of the four canal borings. The canal wells were constructed of 2-in. I.D., schedule 5, flush joint stainless steel pipe. Well screens consisted of 10-ft lengths of wire wrap stainless steel with 0.01-in. slot openings. Upon termination of the boring, a minimal 2-ft layer of bentonite pellets was placed in the bottom of the boring to fill the void left by the sample spoon and to separate the natural soils from the fill materials. A stainless steel well was then inserted into the borehole through the hollow stem augers and positioned approximately 2 ft above the top of the lower bentonite seal (Fig. 4). The annulus between the borehole and the well casing was backfilled to above the well screen using fine silica sand.

During placement of the sand, bridging occurred in the annular space between the well screen and the augers. The bridging appeared to be caused by the highly viscous nature of the nonaqueous phase liquids (NAPL) that comprise some of the waste materials present in Love Canal. Bridging of the sand was mitigated by withdrawing the hollow stem augers from the borehole up to the elevation where the NAPL was first encountered and placing the sand pack in an unsupported borehole. Fortunately, the boreholes maintained their integrity and did not collapse, probably due to the viscous nature of the NAPL. A 2-ft layer of bentonite pellets was placed above the silica sand pack, and the remainder of the borehole annular space was filled with alternating layers of sand and bentonite pellets. A surface seal of 2 ft of bentonite pellets and a 4-ft thick cement/bentonite plug were placed at each well to inhibit infiltration of surface water.



Figure 4 Typical Canal Well Installation

BOREHOLE SITE PREPARATION

In 1984, when the canal cap was extended and the 40-mil HDPE liner was placed, an 18-in. combination of "clean" silty sand and topsoil was placed over the HPDE liner to allow site access, to protect the liner against the effects of ultraviolet light and to sustain vegetation. A crop of grass has been established on the cover material.

Because the cover material was obtained off-site, the cap surface is considered clean; work conducted at the site must maintain and protect the clean surface. At most hazardous waste sites where borings are made with hollow stem augers, cuttings generated by the augers are allowed to collect on the ground surface or some type of temporary plastic sheeting before being transferred to a disposal drum (if required). This method of auger cuttings management was deemed inappropriate due to the likelihood of subsurface waste materials contaminating the clean ground surface, as a result of drilling and well installation operations. Preparation of each borehole site required the installation of a HDPE pipe and boot system to allow penetration of the HDPE liner and placement of a spill containment system to protect the ground surface.

HDPE PIPE AND BOOT SYSTEM

Borings in the canal required penetration of the 40-mil HDPE liner overlying the canal. NYSDEC required that all necessary measures be taken to protect and maintain the integrity of the liner wherever it was penetrated by a borehole or well. Numerous methods for penetrating the liner were proposed, but a system using a flexible "top hat" section boot of 40-mil HDPE sleeved over a rigid section of HDPE pipe was selected.

The HDPE pipe and boot system (Fig. 5) was utilized to allow penetration of the liner by hollow stem augers while protecting and maintaining the integrity of the liner. The system consisted of a 12-in. I.D., 13-in. O.D., by 18-in. long rigid sections of HDPE pipe with a flexible 40-mil HDPE boot sleeved over the pipe. The purpose of the HDPE pipe was to add rigidity to the boot while at the same time providing a redundant level of reliable protection against the infiltration of water if the weld on the flexible boot failed.

Each HDPE pipe and boot was preassembled and installed by an experienced liner subcontractor. Access to the liner was gained by carefully hand-excavating approximately 18 in. of silty sand soil overlying the liner. The installation was performed by first welding the HDPE pipe section to the liner. The 40-mil HDPE boot was then sleeved down over the pipe and welded to the liner. The welding was performed using an HDPE hot extrusion welding gun. The area at the top of the pipe where the pipe was sleeved over the boot was sealed, made waterproof with butyl rubber and secured with a stainless steel band and clamp. Each pipe and boot was manufactured and installed for approximately \$350. Depending on weather conditions, the liner contractor was able to install three to four boots per day.

SECTION VIEW

NUME EXCAVATED AREA REFELED ATTER MOTALLATION OF BOOT SETTY AND/TOPBOLI MULTIP MOTALLATION OF BOOT MULTIP MOTALLATION MULTIP MOTALLATION OF BOOT MULTIP MOTALLATION MULTIP MOTALLATION OF BOOT MULTIP MOTALLATION



HDPE Pipe and Boot System (Not to Scale)

SPILL CONTAINMENT SYSTEM

Primary, secondary and tertiary containment systems were devised to effectively manage the auger cuttings, to protect the clean ground surface at each proposed well location and to be compatible with the previously installed HDPE pipe and boot system.

The primary containment system consisted of a 10-in. I.D., 6ft long steel casing and a galvanized steel farm stock tank which had been modified to fit over the previously installed HDPE pipe and boot. Prior to drilling, the stock tank was placed over the HDPE pipe and boot assembly. The steel casing was inserted through the HDPE pipe and advanced about 3 ft into the soil below the HDPE liner. The conductor casing was secured to the drill rig by means of a heavily reinforced steel bracket (Fig. 5 and 6).

The steel casing served as a conduit through which auger cuttings could come to the surface. Additionally, the steel casing protected the HDPE pipe and boot from the rotational forces of the hollow stem augers. The purpose of the bracket was to prevent rotation of the conductor casing when the augers were rotated.

As auger cuttings were brought to the surface through the conductor casing, they were discharged to and collected in the stock tank. A rubber or polyethylene bladder was placed around the top of the conductor casing and extended over the top of the HDPE boot to prevent auger cuttings from dropping between the stock tank and the boot. As cuttings accumulated in the stock tank, they were periodically transferred into 55-gal drums for on-site storage.



Figure 6 Section View—Canal Boring Set-Up

The conductor casing, securing bracket and stock tank cost approximately \$400, including materials and labor costs associated with welding and assembly. The system was designed so that each component could be disassembled and decontaminated.

Secondary containment of spills was provided by placement of a 25 ft \times 45 ft sheet of 40-mil HDPE at each borehole location (Fig. 6 and 7). The sheet of HDPE was then overlaid by six 4 ft \times 8 ft sheets of $\frac{3}{4}$ in. thick plywood. Four-mil polyethylene was then placed over the sheets of plywood and HDPE to provide a third level of protection. Curbs were formed at the edges of the sheet of HDPE by rolling each edge of the 4-mil polyethylene around 4 in. \times 4 in. wood timbers. The timber curbs created a reservoir which, in the event of accidental spillage of contaminated borehole cuttings or borehole fluids, would contain the spilled materials and prevent contamination of the ground surface.

The ground protection system also delineated work areas and

areas where specific levels of protective equipment were required (i.e., level B vs. level C). Upon completion of each boring, the spill containment control system was disassembled by the drilling team. The 4-mil polyethylene, including contaminants which had spilled on it, was rolled up and placed in a 55-gal drum. The sheets of plywood and HDPE were moved to the next drilling location and reused, if possible.

Each canal well location was set up at a cost of approximately \$175, including labor and materials. The sheets of 40-mil HDPE, purchased at a cost of \$450 each, were reused for the entire project.



Figure 7 Plan View—Canal Boring Set-Up



Equipment Decon Pad & Spray Screen

DECONTAMINATION

The drilling equipment and tools used to install the canal wells required extensive decontamination prior to use at the next location. Decontamination of the drilling equipment was performed at the heavy equipment decontamination area located at the south



Figure 9 Drilling Equipment Decontamination Flow Chart

end of the Love Canal site near Frontier Avenue (Fig. 2). The decontamination area consisted of a concrete pad which sloped to a centrally located manhole and a sump which drained to the barrier drain system. The concrete pad was encircled by bituminous berms to prevent flow away from the manhole and sump.

Because steam-cleaning was part of the decontamination procedure and because there tends to be a large amount of overspray (as with any steam-cleaning process), a method was devised to control the overspray. A 16-ft high splash curtain was erected around the equipment decontamination area (Fig. 8). The splash curtain was constructed of polyethylene tarps supported by rope and 2-in. I.D. by 12-ft long steel pipes placed in 55-gal drums of sand topped with concrete. The cost of the materials for the spray curtain was approximately \$500, and the system was erected with only a few hours of labor by the decontamination team. Decontamination fluids collected on the concrete pad were filtered through a sandbag berm placed around the manhole and discharged to the Love Canal Wastewater Treatment Plant through the barrier drain system.

When each well was completely installed, the contaminated drilling tools had to be transported to the equipment decontamination area. Drilling tools used to install the canal wells were considered highly contaminated and could only be transported to the equipment decontamination pad within the confines of the Love Canal perimeter fence. Because no access roads within the perimeter fence directly accessed the decontamination pad, and because it was not always necessary to decontaminate the ATV drill rig, a small farm tractor equipped with a front-end bucket and hydraulic lift platform was used to transport drilling tools to and from the decontamination area.

Contamination of the tractor and ground surface resulting from soil dropping off the drilling tools was prevented by completely encapsulating the drilling tools with disposable polyethylene or, in the case of small tools, placing them in sealed 55-gal drums during transport to the equipment decontamination area. Upon arrival at the decontamination area, the equipment was unloaded, the polyethylene was placed in a 55-gal drum and decontamination was completed according to the procedures established for decontamination of drilling equipment (Fig. 9).

Because of the concentrated wastes encountered in the canal, it was concluded that it would be difficult to completely decontaminate the drilling tools. As a result, the hollow stem augers, drill rods, split-spoon samplers and accessory drilling equipment (e.g., tape measures, hoes, shovels and wrenches) used to make the canal borings and install the canal wells were dedicated to and left on the Love Canal site at the completion of the project.

CONCLUSIONS

Three canal wells were installed in wastes in the Love Canal using specialized, innovative and relatively inexpensive drilling methods and procedures. Utmost care was taken to minimize the impact to the environment and workers and to protect and maintain the integrity of the existing remedial systems. This protection was accomplished by: (1) using an HDPE pipe and boot system for access through the canal cap, (2) using stock tanks and steel conductor casing to manage auger cuttings, (3) using 40mil HDPE and polyethylene as a spill containment liner system beneath and around each drilling location and (4) using contaminant reduction decontamination procedures. The above procedures could be adapted for use at other hazardous waste sites.

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Groundwater Studies, Case Histories And Applied Modeling

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ABSTRACT

Identification and abatement of contaminants in groundwater has captured the attention of Federal and state regulators and the public within the last five years. Prior to passage of RCRA, the impact of accepted waste handling practices under groundwater resources went largely unnoticed. With the passage of RCRA and the subsequent 1984 RCRA Amendments, new energies have been directed at this problem. The evolution of this technology is best demonstrated by reviewing a case study involving a site investigation which was conducted to characterize existing contaminate pathways.

The selected case study involves a manufacturing facility (hereafter referred to as Site A) which included metal finishing operations. The majority of the metal cleaning performed in association with the metal finishing process was conducted within vapor degreasers utilizing the cleaning solvents trichloroethylene and 1,1,1-trichloroethane. Review of the case study of Site A includes the use of the computer model "Random-Walk" to evaluate interim groundwater remedial action alternatives. Model results are presented describing the impact of development of the recommended groundwater recovery system.

INTRODUCTION

Public scrutiny of activities resulting in groundwater contamination has intensified within the last 5 years. As a result, industries, governmental regulatory agencies and private sector service companies have intensified their efforts to utilize existing technologies and, where necessary, develop new innovative approaches to address the issues associated with proper groundwater management. A review of current technologies is presented by examining a case study of a manufacturing facility having volatile organic chemical (VOC) contamination of both soils and groundwater, hereafter referred to as Site A.

Site A involves a manufacturing facility which includes a metal finishing process. Metal cleaning, which is conducted in association with the metal finishing process, was performed within vapor degreasers and at other miscellaneous stations utilizing the solvents trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA). It is believed that use of TCE and TCA at Site A began in mid-1961 and continued until January 1985, and June 1983, respectively. These solvents have since been replaced by alkaline cleaners. As a result of past VOC management practices, it is estimated that approximately 2,200 gal of TCE and TCA have been released into the soil and have entered the groundwater system. Eight areas within Site A and two off-site areas have been identified as potential sources of contamination (Fig. 1). The ten potential sources are:

Borrow Pit

- Sludge Lagoons
- Effluent Discharge Pipe
- Railroad Area
- Front Yard Area
- Courtyard Area
- Manufacturing Area
- Drainage Area
- Roadways
- Off-Site Sources Not Related to Site A

SITE INVESTIGATIONS

Beginning in 1984, an investigative program was implemented at Site A to delineate the plume of contaminated groundwater. To date, the plume delineation program has consisted of installing a network of monitoring wells with subsequent sampling and analysis to determine the extent and degree of degradation of the groundwater that has occurred. This investigation was a phased operation with the initial phase being the installation of on-site monitoring wells, the second phase being the installation of monitoring wells immediately off-site and the third phase being the installation of a comprehensive ring of outer monitoring wells. This activity resulted in the installation of a total of 44 monitoring well clusters.

Monitoring well locations can be separated into 17 on-site and 27 off-site clusters. Each cluster contains two to four wells screened at different depth intervals. The locations of the monitoring wells are shown in Fig. 1. Sampling included determining the groundwater level and performing groundwater analysis in an effort to determine plume geometry.

Geologic cross-sections constructed from data obtained during the site investigation (Figs. 2 and 3) illustrate the hydrogeologic conditions underlying Site A. Cross-section locations are shown in Fig. 1. Note that the hydrogeologic system consists of an upper (alluvial) and lower (Ogallala) aquifer separated by an aquitard.

The "leaky" character of the aquitard permits a hydraulic connection to develop between the two flow systems. The upper aquifer consists of alluvial material and is approximately 20 ft thick. The Ogallala formation (a minimum of 400 ft thick) forms the lower aquifer and consists of interbedded sands, gravels, silts, clays and sandstone.

The regional water table in the alluvial aquifer is located approximately 5 ft below the ground surface and ranges from approximately 6.5 to 10 ft above the Ogallala aquifer, indicating a potential head difference between the two aquifers. In the alluvial aquifer, regional flow is in the west to east direction. A northerly component of flow, however, was observed west of the irrigation canal (Fig. 1) during the summer. It is suspected that this anomaly was caused by seepage loss from the canal. The flow



pattern in the Ogallala aquifer fluctuates, depending upon local pumping activities and seasonal variations.

ANALYTICAL RESULTS

Following the installation of groundwater monitoring wells, selected groundwater sampling was performed in April, June and August 1985, with comprehensive groundwater sampling conducted in November 1985. For purposes of this study, the contaminant plume boundary was defined as being where the concentration of total VOCs exceeded 10 μ g/l. Insufficient data representative of lower concentrations were available to properly define isopleths of lower value.

Results from groundwater sampling conducted within the alluvial aquifer found total VOC concentrations of 2,310 and 2,211 $\nu g/l$ in cluster site #46, while total VOC concentrations in cluster site #41 for the same time period were 25 and 35 $\mu g/l$, respectively. These data are not conclusive in determining whether the reported concentrations originated from Site A or an isolated offsite source. Two hypotheses addressing this anomaly include: (1) an intermittent release of contaminants from an active off-site source; and/or (2) contaminant dilution resulting from use of a local irrigation canal during one of the sampling events resulting in the separation of the plume into two zones within the alluvial aquifer. Should the latter hypothesis prove valid, the plume component located east of the canal would continue in an eastward migration, while the western component is temporarily controlled and/or diverted to a northerly direction.

The southern edge of the plume boundary within the alluvial aquifer is believed to extend south of cluster site #39. Total VOC concentrations in this monitoring well cluster ranged from 44 to 47 μ g/l. No monitoring well clusters are located south of cluster site #39; therefore, the plume boundary in this direction cannot be defined.

Based upon a review of available analytical data, we concluded that regional contaminant movement within the alluvial aquifer appears to coincide with the west to east direction of groundwater flow. Factors which may affect local plume movement include pumping from deep production wells. Such actions would enhance the vertical groundwater movement and may result in transport of contaminants into the Ogallala aquifer. Further, a northerly component of flow may develop west of the irrigation canal during summer months as a result of seepage.

Groundwater samples collected from monitoring well clusters screened into the Ogallala aquifer showed VOC concentrations in cluster site #35 (see Fig. 1) of 639 and 949 μ g/l. At depths within the intermediate Ogallala aquifer (approximately 101 to 170 ft below the surface), VOC concentrations ranging from 660 to 1796 μ g/l in cluster site #26 were detected. Similar to results reported for the alluvial aquifer, the southern edge of the plume in the Ogallala aquifer appears to extend beyond cluster site #39 (see Fig. 1). VOC concentrations of 452 and 896 μ g/l were identified at this cluster site.

The northern and western boundaries of the plume within the Ogallala aquifer are influenced somewhat by municipal wells 53-1 and 59-1. Groundwater movement in the upper and intermediate zones of the Ogallala aquifer is toward these wells. This observation is substantiated by the fact that VOC concentrations ranging from 19 to 28 μ g/l and 90 to 155 μ g/l were reported at cluster sites #25 and #26, respectively.

DEVELOPMENT OF REMEDIAL ACTION ALTERNATIVES

Based upon the results of the site investigations, interim remedial action alternatives were developed. The objectives of the interim remedial action include:

- Contain, recover and treat grossly contaminated groundwater (VOC levels greater than 500 µg/l) both on-site and off-site;
- Divert any remaining contamination from the nearby municipal water supply wells
- Design, construct and operate groundwater treatment systems capable of meeting multiple discharge limits of 5, 50, 100 and $500 \mu g/l$
- Collect information and data resulting from implementation of the selected remedial action plan to further identify plume boundaries, monitor plume cleanup and identify any remaining sources

Final remedial action alternatives will be implemented once additional site investigations are conducted and final permit limits with the appropriate regulating agencies are negotiated.

The recommended remedial action technology assessment, alternative development and screening procedures for Site A consisted of the following steps:

Identify General Response Actions

- Identify site problems and pathways of contamination (remedial investigation) and define cleanup goals and objectives
- Identify general response actions that address site problems and meet cleanup goals and objectives

Identify and Screen Technologies and Develop Remedial Alternatives

- Identify possible technologies in each general response action; then screen the technologies to eliminate inapplicable and infeasible technologies based on site conditions
- Assemble technologies into operable units based on the remaining feasible technologies

Screen Public Health, Environmental, and Cost Factors

- Screen alternatives, eliminating those that have significant adverse impacts or that obviously do not adequately protect the environment, public health and public welfare
- Screen alternatives, eliminating those that are an order of magnitude higher in cost than other alternatives, but do not provide significantly greater environmental or public health benefits or technical reliability

Based upon the above criteria, the general response actions and associated remedial technologies presented in Table 1 were considered in developing interim remedial actions for Site A.

 Table 1

 General Response Actions and Associated Remedial Technologies

Ge neral Response Actio n	Technologies					
No Action	Some monitoring and analyses					
Cont ainment	Capping; groundwater containment barrier walls; bulkheads, gas barriers, hydrodynamic control					
Pumping	Groundwater pumping					
On-Site Treatment	Incineration; solidification, land treatment; bio- logical, chemical and physical treatment					
Off-Site Treatment	Incineration; biological, chemical, and physical treatment					
In Situ Treatment	Permeable treatment beds; bioreclamation soil flushing; neutralization; land farming					

Since the focus of the remedial action alternatives is to control the extent of off-site contamination by controlling the primary transport medium (groundwater), those individual technologies which specifically address groundwater contamination were considered next. A summary of specific remedial action alternatives for contaminated groundwater which were evaluated for implementation at Site A is presented in Table 2.

Each specific remedial action technology for contaminated groundwater (Table 2) was next rated and ranked into a relative order on the basis of engineering feasibility, effectiveness, maintenance, service life and cost. Each technology was rated for each criterion based on a scale ranging from 1 to 10, with a value of 1 being best and a value of 10 being unacceptable. Results of this evaluation are presented in Table 3.

Table 2
Summary of Specific Remedial Action Technologies for
Contaminated Groundwater

Technology	Functions	Application/Restrictions
Containment (Impermeable Barriers) • grout curtain • slurry wall • sheet piling	Upgradient from or around sites, diverts uncontaminated groundwater flow away from wastes. Downslope or around sites contains/collects con- taminated groundwater to limit extent of aquifer pollution or protect off-site wells.	Applicable to all land disposal sites and surface impoundments with groundwater contamination. Requires expensive preconstruction geotechnical evaluation, limited to bedrock depths of under 60 ft. Compatibility of wastes with grouts and, to a lesser extent, slurry walls, has not been fully tested. Grout not suitable to poorly permeable soils.
Hydrodynamic Control	Contains or recovers the plume within the radius of influence of an extraction well. Creates a hydraulic barrier to ground- water flow. Allows water with- in the plume to be pumped, treated and pumped back into the aquifer or discharged to a surface body.	Applicable to containment of plumes where the boundaries of contamination are well defined. Changes in plume volume and site characteristics result in costly and frequent monitoring.
Groundwater Pumping	Plume containment and/or cleanup through pumping which effectively reverses or stops the advancement of the contaminant front. Combines containment with cleanup of affected portion of aquifer. May be combined with re- charge.	Applicable to sites underlain by permeable, coarse-grained deposits. No guarantee that the approach will intercept entire plume of contam- inated water. Systems are flexible and can be readily adjusted to ac- count for changes in the plume.
Biological Treatment	Destroys certain groundwater contaminants through bac- terial activity.	Applicable to treatment of contam- inated groundwater containing higher levels of organics. May be susceptible to shock loads.
Physical Treatment • Aeration	Transfer of volatile organics from the water to air through aeration, resulting in treated water with very low VOC concentrations.	Applicable to treatment of con- taminated waters containing vary- ing degrees of volatile organics. Capable of removing over 99% of volatile organics from a contam- inated groundwater.
• Activated Carbon	Applicable to removal of high molecular weight organics, in- soluble or nonionized organics.	Adsorption of groundwater con- taminants by contacting ground- water with carbon, which selectively adsorbs hazardous materials by physical and/or chemical forces.
Bioreclamation	Bacterial degradation/re- moval of petrochemical con- taminants and other organics as groundwater is recycled be- tween pump stations.	Not effective for groundwater con- taminated by heavy metals, certain chlorinated organics, or other nonbiodegradables; short-term treatment only; may be very costly.

Based on the selection criteria used to evaluate the remedial action alternatives, groundwater pumping in conjunction with air stripping was selected as the most applicable technology for interim remediation at Site A. Groundwater pumping will address the primary mechanism (groundwater) by which contamination is transported off-site. Air stripping will provide for the removal of VOCs from the groundwater with very low levels remaining after treatment.

GROUNDWATER MODELING

To evaluate groundwater pumping alternatives and design an effective recovery system, the solute transport model "Random-Walk" was utilized. Random-Walk is a two-dimensional model in which groundwater flow equations are solved using finite-difference approximations. Model results include identification of the plume's geometry, movement and contaminant concentrations at different time periods, i.e., 30 days. The modeling objective was to provide sufficient information to design a groundwater recovery system to initiate restoration of the aquifers and provide containment for those areas where VOC concentrations exceed 500 $\mu g/l$.

As previously indicated, the Random-Walk model uses the finite-difference method involving the formation of a grid which is further subdivided into cells. A particle-in-a-cell and Random-Walk technique are used in the solute transport portion of the code to address the effects of convection and dispersion. In Random-Walk, a particle is characterized as a dimensionless mass with a specific concentration which is averaged and distributed uniformly throughout a cell. The model may be used to simulate time-varying pumpage, well injection, man-made or artificial recharge and the interaction of flow between surface water and groundwater.

For modeling purposes, the alluvial and Ogallala aquifers were treated as a single homogeneous aquifer and subdivided into four zones. Random-Walk does not allow for separation of the aquifers. The zones described above include the screened intervals of the monitoring wells at 0 to 30 ft, 31 to 100 ft, 101 to 170 ft and 171 to 430 ft. These four zones were chosen because they provide the best overall data for determining the total mass of the plume.

The following are assumptions which were incorporated into the Random-Walk model for each of the four zones:

- Aquifer system is homogeneous-isotropic
- Aquifer system is confined and non-leaky
- Storage coefficient, transmissivity and hydraulic conductivity were computed assuming a discharging well penetrating the entire thickness of the aquifer
- Instantaneous removal of water with decline in head
- The irrigation canal was treated as a constant head boundary using the image well theory. This theory is a means of developing an artificial recharge boundary. This canal was not modeled during non-flow periods because it does not cause any changes in groundwater and/or contaminant movement under these conditions.
- Longitudinal and transverse dispersion were estimated to be 30 and 3 ft, respectively, where longitudinal dispersion is generally ten times larger than transverse dispersion
- Half-line or biological breakdown of the contaminants was considered to be minimal; this assumption represents a worst case situation

Input to the model was based on data from previous reports addressing the results from a 73-hr pump test on process water supply well M-3 located on Site A property. Even though well M-3 is screened in the Ogallala aquifer, it was assumed that similar hydrologic characteristics would also be observed in the alluvial aquifer. Further, the hydrologic characteristics from the alluvial aquifer were not used as model input for the following reasons:

• Available input data for the alluvial aquifer are incomplete. Additional parameters (i.e., transmissivity, storage coefficient)

Table 3 Comparison of Remedial Technologies

<u></u>	TECHN	CAL	<u>.</u>		SERVICE	
	FEASIBILITY	PERFORMANCE	MAINTENANCE	LIFE	COST	TOTAL
SLURRY WALLS	10	6	2	1	9	28
GROUT CURTAIN	10	8	2	1	9	30
SHEET PILING	10	5	2	1	7	25
HYDRODYNAMIC CONTROL	6	6	5	5	5	27
GROUNDWATER PUMPING	3	3	5	3	4	18
PERMEABLE TREATMENT BED	X5 6	4	2	3	9	28
BIOLOGICAL TREATMENT	5	5	8	3	5	26
AIR STRIPPING	2	1	4	4	3	14
CARBON ADSORPTION	4	5	5	4	4	22
BIORECLAMATIC	W 5	3	4	3	6	21

are needed to initiate model simulations. A pump test is recommended.

- Since the mass of contamination is greater in the Ogallala, it is reasonable to use transport characteristics of the Ogallala as model input to predict movement of contaminants.
- A condition of the model (uniform-homogeneous aquifer system) prohibits the use of values from two separate aquifers.

A list of initial input data used in the Random-Walk model is

presented in Table 4. Note that the retardation coefficient listed as input data is a ratio of travel times between the solute and the contaminant. Half-life, which is also an input parameter, is the time required for the biodegradation or breakdown of contaminants.

Table 4	
Initial Input Data for Solute Transpor	1 Model

Parameter	Value	Unit(s)			
Transmissivity	91300	Gallons per day per foot			
Storage Coefficient	0.0004	••			
Hydraulic Conductivity Porosity	500 0.30	Gallons per day per square foot			
Longitudinal Dispersivity	30	Feet			
Transverse Dispersivity	3	Feet			
Regional/X-Flow	0.30	Feet per day			
Regional/Y-Flow	0.003	Feet per day			
Average Aguifer Thickness	425	Feet			
Retardation Coefficient	1.5	••			
Half-life of Contaminant	1E32	Days			
Starting Mass Per Particle	4.98	Pounds			

A map illustrating the proposed layout for the solute transport model is presented in Fig. 4.

A grid size of 200 ft by 200 ft was chosen to depict the areal extent of the plume.

Groundwater quality data were next input into the model. To accomplish this, contaminate concentrations $(\mu g/l)$ were converted into a mass (lb) prior to data entry. The following steps were taken in making this conversion.

- Division of the aquifer system into 4 zones (0 to 30 ft, 31 to 101 ft, 101 to 170 ft and 171 to 430 ft)
- Overlay map window on the contaminant contour map



Figure 4 Particle Cells Superimposed Over Study Area

- Compute the particle mass of the plume in each aquifer zone by assigning a value to a cell in the model; the total mass of the plume is computed by summing the particle mass in each cell
- Divide the total particle mass of the plume system by the number of particles to obtain the starting mass per particle

The following equation was used to convert a concentration to a mass:

$$M_{cell} = N_e \star M \star C_{AVG} \star RT \star AX \star AY \star C_1 \star C_2 \qquad (1)$$

Where:

Mcell	= Mass of cell, g
Ne	= Porosity
М	= Thickness of aquifer zone, ft
CAVG	= Average concentration for cell, $\mu g/l$
RT	= Retardation coefficient
AX,AY	= Cell side lengths, ft
C_1, C_2	= Conversion factors

Following input of all initial data into the model, four different alternatives (i.e., A, B, C and D) were simulated. Each alternative involved different numbers of recovery wells, recovery well locations and discharge rates assigned to the recovery wells. The results of the model simulations for each alternative scenario provided information which could be used as a basis to design the groundwater recovery system. Process well M-3 was considered a fixed recovery well in all simulations.

CONCLUSIONS

Alternative D, consisting of three recovery wells (RC1, RC2 and RC3), was selected as the most effective remedial design because of its ability to limit plume movement and effectively reduce the total mass of the plume. The discharge rates of these wells were designed to be 846,000, 1,080,000 and 864,000 gal/ day, respectively. Fig. 4 shows the locations of the proposed recovery wells.

Eight different model runs or simulations were made using this alternative. Simulation times ranged from 1 day to 5 yr (Table 5). The initial geometry of the plume and total VOC concentrations within the plume were simulated using an interval of 1 day. The total number of system particles in this simulation was 4086. After 30 days of simulation, model results indicated a 5.9% re-

duction in the total mass of the plume. Simulation times were chosen at random. Subsequent simulation times of 150, 330, 730 and 1825 days showed 28.44%, 44.5%, 64.32% and 86.88% (5 yr) reductions in total plume mass, respectively.

Additional information computed by the model includes the drawdown effects caused by pumping the recovery wells. The results are an estimation of the amount of head loss or the level, in feet, which the water table will be lowered in the area. The estimated drawdowns in recovery wells (RC2 and RC3) were 18 ft and 13 ft, respectively. These drawdowns will occur immediately upon startup of the system. These values do not appear to change with time. Estimated head losses in municipal wells 59-1 and 67-1 ranged from 1 to 2 ft, approximately 3 ft in wells 53-1 and 65-1 and 3 ft in Site A process water supply well M-3.

 Table 5

 Results of Interim Groundwater Modeling

 Alternative D, Recommended Alternative

Simulation (Dave)	Number o	of Particles	Removed	Total System Particles	X Particles
(0633)			NVE	raiticica	NCHIOTEU
1		200		4086	
30	15	200	25	3846	5.90
90	78	419	107	3242	20.66
150	130	8542	180	2924	28.44
210	148	1019	253	2666	34.76
270	27	142	43	2454	39.95
330	32	110	44	2268	44.50
450	54	193	80	1941	52.50
570	38	120	70	1713	58.08
690	29	128	51	1505	63.17
730	6	33	8	1458	64.32
913	45	140	46	1227	70.00
1095	49	97	39	1095	73.20
1460	87	162	53	740	81.89
1825	51	114	39	536	86.88

Alternative D will provide for the partial containment and restoration of the alluvial aquifer. Since the purpose of the interim phase is protection of drinking water supplies, emphasis was placed on containment of contaminants and restoration of the Ogallala aquifer. Equal emphasis will be concentrated on each flow system for the final remediation phase. Based upon the information supplied by the Random-Walk model, appropriate air stripper designs now can be developed.

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The NIKE Missile Site Investigation Program

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ABSTRACT

The U.S. Army's NIKE missile system was built to provide protection from aerial attack to major military installations as well as key metropolitan areas from approximately 1955 to 1975. During this period, 292 missile sites were operational in the continental United States. Operations at the sites required assembly, maintenance and storage of components of military hardware as well as handling, disposal and storage of fuels, cleaners, solvents, hydraulic fluids and other materials necessary to maintain a NIKE missile battery operation.

As with any use of military or industrial hardware, the generation of hazardous waste materials was a typical byproduct. Because of past waste management practices, the Army wished to determine if environmental degradation was occurring at these sites. To investigate this possibility, provisions of the 1984 Defense Appropriations Act were implemented to permit the Defense Department to include specific, formerly owned, NIKE sites for investigations.

The role of the Huntsville Division of the Corps of Engineers was that of central manager during the inventory phase of the DERP. Further studies, if required, would be the responsibility of HND for ordnance contaminated sites, and would be the responsibility of the Missouri River Division for hazardous and toxic contaminated sites.

This paper presents background information on the NIKE missile program, describes a typical site layout, presents general information about the site operations and briefly discusses some of the site-specific findings from 11 sites that have been investigated by Law Environmental Services. Data from nine of the 11 sites have been evaluated, and results indicate that little contamination was evident in the monitoring wells, soil and surface water samples associated with the sites.

INTRODUCTION

The Department of Defense (DOD) conducts a number of industrial processes and manufacturing operations that are similar to private industry. In the late 1970s, DOD became aware of the negative impacts of what previously were considered acceptable disposal practices of waste materials associated with these processes and operations. In response to that knowledge, programs were developed between 1975 and 1978 by each service component to identify and assess potential contamination on active military installations. Authority to address problems at formerly used DOD sites was lacking since funds could not be spent on sites not owned by DOD.

The passage of the 1984 Defense Appropriations Act corrected this situation. Specific language in the Act directed DOD to extend its efforts to include sites formerly used by DOD and broaden the definition of "hazard" to include unsafe structures and debris which were to be abandoned or had been abandoned upon termination of their military use. The Act directed that the Secretary of Defense assume overall management of the program to assure a consistent approach and adequate resource allocation.

The objective of this investigation was to assess the potential for toxic or hazardous contamination related to all former NIKE missile sites located throughout the continental United States (CONUS). Contamination included hazardous or toxic substances found in the groundwater, surface water and soil, with contaminants specified by regulatory criteria. To fulfill this objective, a two-phase program was developed. Phase I involved a generic study of the NIKE program that included the following work elements:

- Review NIKE site listing forms
- Determine agencies involved with the NIKE battery
- Perform archive search to obtain technical manuals, training manuals, operating procedures and field manuals
- Meet with previous NIKE site operators
- Review USATHAMA reports to assist in documenting contaminant sources at NIKE installations
- Locate "As-Built" drawings
- Obtain generic and site specific deactivation plans
- Prepare a hazardous substance list
- Identify potential contamination sources
- · Identify hazardous operational practices

Phase II of this investigation involved specific field investigations and analytical programs at selected NIKE sites across the United States. The following sections of this paper briefly describe the NIKE program background, typical operating units at NIKE sites, potential contamination source areas and potential contaminants at NIKE sites. Finally, the paper briefly discusses some of the site-specific findings from nine of the sites that were investigated.

NIKE PROGRAM BACKGROUND

NIKE Ajax and NIKE Hercules missiles were deployed by the United States Army throughout the continental United States to protect major metropolitan areas and strategic military installations from aerial attack. The NIKE system was generally operational from the early 1950s to the mid-1970s. Maintenance of the missile batteries in a combat-ready status required the storage, handling and disposal of missile components as well as solvents, fuels, hydraulic fluids, paints and other materials required for support functions.

During the period of its operational life, the NIKE Ajax system remained essentially unchanged. However, a second generation NIKE system, NIKE Hercules, was under development by the mid-1950s. NIKE Ajax batteries were similar in design and construction with all units having similar operational components. Beginning in late 1958, selected NIKE Ajax batteries began conversion to the more advanced NIKE Hercules system. However, it was not until early 1964 that the last NIKE Ajax battery was deactivated and the entire operational system employed the NIKE Hercules missile. The primary role of the NIKE Hercules system was its ability to attack high-speed, high-flying aircraft formations with a single nuclear warhead. The NIKE Ajax system used liquid fuels which were highly toxic and had to be handled with extreme care. The NIKE Hercules missiles made more use of solid fuel which significantly simplified the fueling and maintenance operations of the missile system.

In 1962 the Army began transferring operation of certain NIKE batteries to National Guard units. Shortly thereafter, deactivation of NIKE batteries began. By 1970, the Army had deactivated more CONUS NIKE sites. National Guard units continued to maintain a few sites until the late 1970s. Some NIKE equipment is still retained in Ft. Bliss for training troops from other North Atlantic Treaty Organization (NATO) countries that still incorporate NIKE missiles in their defense programs.¹

NIKE SYSTEM DESCRIPTION

A NIKE site typically consisted of two separate and distinct operating units. These units included the Launcher Area and the Integrated Fire Control (IFC) Area. The Launcher Area generally was located on approximately 40-60 acres, although each site could vary significantly in size and shape. The IFC Area generally



Figure 1 Typical Site Plan for a NIKE Launcher Area

ranged in size from 10-50 acres. The Barracks facilities were either incorporated as part of the Launcher Area or the IFC Area, or a third separate and distinct Family Housing Area was constructed. The Launcher Area and the IFC Area generally were located 1-2 miles apart to facilitate necessary distance and equipment restrictions that involved the successful interaction of the two areas.

The layout of structures within each area appears to have been site-specific, although different sites have many similar structures. Fig. 1 illustrates a generalized NIKE Launcher Area. For the Launcher Area, the key structural units include the missile assembly building, the warhead building and three magazine (missile storage)/launch units. Although not shown in the figure, the IFC Area generally included the radar units, a generator building, general storage and supply buildings and, in most cases, the motorpool. At some sites, the motorpool could have been located at the Launcher Area. These sites also generally included a number of waste disposal units including sump and draining systems, seepage pits, septic tanks with infiltration wells for liquid waste disposal and occasionally on-site landfills.

GENERAL UNIT OPERATIONS

The Launcher Area of a NIKE site was the location where the missiles and warheads were assembled, maintained and prepared for firing. The missiles arrived at the site disassembled as 13 specific components. All operations necessary to make the missile flight ready were then conducted in specific locations in the Launcher Area. In general, routine maintenance and checking procedures were performed on the missile at the Launcher Area.

The IFC Area at a site contained all the radar, guidance, electronic and communications equipment needed to identify incoming targets, launch missiles and direct missiles in flight.

POTENTIAL CONTAMINATION SOURCE AREAS

Because of the nature of site operations, several individual sources of potential contamination existed on former NIKE sites.²⁴ The generalized site diagram for the Launcher Area is intended to indicate the major structural units for reference to areas that could have resulted in waste. As previously stated, the location of these units on any given site varied with the terrain and the general arrangement of facilities.

Waste Fluid Disposal

Probably the most significant general practice that occurred that could have led to contamination was the method of dealing with waste fluids. Standard operating practices dictated that waste fluids were to be accumulated in POL (Petroleum, Oils, Lubricants) barrels which were periodically transported to disposal sites. However, waste fluids were reported to have been disposed of directly to the soil surface on occasion, rather than being placed in POL barrels, resulting in localized contamination. The POL barrel contents reportedly have been dumped occasionally in a random "unofficial" manner, both on-site and offsite. Locations of such dumps are predictable only by general site characteristics.

Missile Assembly Drainage and Seepage System

The missile assembly building operations involved the use of various solvents, anticorrosion products and paints as the missiles were assembled and disassembled. The building was equipped with a full-length drainage system. Spilled or waste materials could be washed or dumped into this drainage system.

Diesel and Fuel Oil Storage Tanks

A number of electric power generators reportedly were used on

NIKE sites, and diesel fuel storage was considerable. Tanks also were used to store fuel oil for heating purposes. These tanks were probably steel, but this could not be documented. It is probable that several tanks were present at each site, holding up to 5,000 gal each. Leakage from fueling and defueling operations and actual tank leakage undoubtedly occurred.

Magazine Sump Seepage Systems

Within the typical NIKE magazine, a floor drainage system permitted waste materials to be washed to a central sump located under the missile elevator shaft. This sump was equipped with a pump to deliver water and waste out of the magazine and into a seepage system. Solvents, paints and hydraulic fluid were supposedly washed to the sump on a routine basis.

Secluded Areas Adapted to "Unofficial" Dumping

Dumping of various wastes was reported as common at NIKE sites. The primary factor affecting the incidence of dumping was convenience. Certain authorized disposal routes were available to NIKE sites. However, utilization of these disposal routes varied from site to site. Solid waste could be delivered to municipal landfills while the Army POL service was responsible for removing waste solvents, oils and paints.

When the landfill was not convenient or the POL was irregular about pickup, other methods were used to dispose of the waste. Rural sites were particularly prone to "unofficial" dumping. Dumping reportedly occurred both on-site and off-site.⁵⁻⁷

Warheading/Fueling Area Drainage System

The potential for contamination in this area is considered to be less than that found in other areas. Liquid fuels rarely were spilled in quantities. The IRFNA (nitric acid), UDMH (dimethyl hydrazine) and ethylene oxide were hazardous, volatile materials and were handled very carefully. It was very rare that quantities of these materials escaped accidentally. In addition, due to the extreme reactivity of these substances, any spillage or leakage that may have resulted in contamination would not persist in the environment for any considerable length of time.

Battery electrolyte reportedly was discarded in this area, therefore modest amounts of lead may have been introduced as a result. However, it is likely that other sources of lead, such as paint, were of much greater magnitude. Sulfates and nitrates in the warheading/fueling area would be insignificant in the concentrations at which they would occur.

Septic Systems

When barracks were located on the Launcher Area, a septic system of significant size was required. Urban and suburban NIKE sites were connected to municipal wastewater systems. However, rural sites required a septic tank and leaching system. Barracks were more often sited at the IFC area, along with the battery administration and other facilities.

Integrated Fire Control (IFC) Area

The IFC Area was less prone to chemical contamination than the Launcher Area. The diversity of chemicals was smaller, and the primary mission of the IFC radar operation did not require significant chemical use. The main units of concern with regard to contamination at the IFC area were the following:

- Motor Pool
- Septic System
- Diesel, Fuel Oil and Gasoline Storage Tanks
- Secluded Areas Adapted to Unofficial Dumping

No site-specific deactivation plans were obtained. The primary information concerning deactivation practices came from the site operator interviews. Two generic deactivation plans^{8,9} were reviewed; however, these plans did not address issues pertaining to chemicals or practices that may have involved contamination. Actual practice of deactivation probably resulted in disposal and/or abandonment of considerable volumes of potentially hazardous materials according to the site interviews. Specific practices varied significantly from site to site.

MASTER CONTAMINANTS LIST

Based on the analysis of site operations, a master list of possible NIKE site contaminants was prepared (Table 1). Each substance identified on the master list was used in significant quantities on NIKE sites and has a high probability of causing contamination if discharged to the environment. Most of the other materials identified in this investigation were eliminated from consideration since the volume of use on NIKE sites was small. Certain chemicals identified in previous investigations conducted by the United States Army Toxic and Hazardous Materials Agency (USATHAMA) were not included on the master list. The primary criteria for not including materials on the master list included:

- The materials were used only in small quantities
- The materials were used with extreme care such that only minor quantities might have been released
- The materials were reactive to the environment such that possible contamination from these materials would have dissipated with time

Specific discussions of the substances comprising the master list, and of certain significant materials that were eliminated from the list, are presented in the following section. Materials on the master list that represent additions relative to previous studies are so designated.

 Table 1

 Master List of Significant Potential NIKE Site Contaminants

NATERIAL	USE. CHARCEPULSTICS	DISPOSAL HETICO
Benzene	Bolvent	Dvaporación, Drainage and Leaching
	General Solvent and Fuel Constituent	Fuel Tark Leakage
Carbon Tetrachloride (Tetrachloromethane)	Sal vers	Evaporation, Drainage and Leaching
Chromium (Chromatem, Chrome (11, IV, and VL)	Decorroding Rissile Parts	Drainage and Leaching. Surface Disposal
Petroleum Hydrocarbons	Puela, Lubricanta, Hydracarbona	Consumed, Fucl Tank Leakage, Spiilage to Soil, FOL Turn-In, Drainage and Leaching, Surface Disposal
Lead {Carbonates and Oxide)	Paints and Dattery Electrolyte	Drainage and Leaching, FOL Turn-In
Perchlorethylene (Tetrachloroethene)	Solvent	Evaporation. Drainage and Leaching
Tolueve	Salvent Constituent of Pucia	Drainage and Leaching Puel Tank Louisage
1,1,1-Trichloroethane	Salvent	Evaporation, Drainage and Leaching
1,1,2-Trichlorgethave	Solvent	Evaporation, Drainage and Leaching
Trichioroethylene	Sol vent.	Swappration, Drainage and Leaching

Benzene

Benzene was probably in use as a solvent in the early stages of the NIKE program but was eliminated from updated standard equipment inventories. It remained in the text of the unrevised portions of the TM 9-1400-250-15/3 operations manual. Benzene was removed from military use due to its toxicity. Benzene is also a common constituent of other solvents and fuels. Gasoline, for example, contains significant amounts of benzene, so that NIKE site contamination from leaking fuel tanks or other solvent use increased the potential for benzene contamination.¹⁰⁻¹²

Carbon Tetrachloride

As indicated in studies of NIKE sites (USATHMA DRXTH-AS-IA-83016), carbon tetrachloride was used in the early portions of the NIKE program. It is a superior solvent and was used extensively for cleaning and degreasing.

Chromium

Chromium originates on NIKE sites in the cleaning materials chromium trioxide and sodium dichromate, as well as in zinc chromate and other paints.

Petroleum Hydrocarbons

Fuels, non-chlorinated solvents, naphthas, lubricants, paints and hydraulic fluid all fall into the class of petroleum hydrocarbons. Because there are thousands of different but similar hydrocarbons, they are considered as a group when dealing with contamination from the materials mentioned above. In sheer quantity, hydrocarbons constitute the most significant potential contaminant of former NIKE sites.

Lead

Lead originates on NIKE sites in battery electrolyte and leadbased paints. Paint disposal at NIKE sites may have caused extensive contamination by lead.

Perchlorethylene

Interviews confirmed the use of perchloroethylene on NIKE sites. It was used as a solvent, probably after carbon tetrachloride use ceased and before the introduction of trichloroethene and trichloroethanes. High-volume use could be expected during that period.

Toluene

Toluene was specified as a cleaning solvent for missile components. It is also a component of fuels and other solvents.

1,1,1-Trichloroethane, 1,1,2-Trichloroethane and Trichloroethene

The use of these solvents was documented previously by USATHMA and was confirmed by this investigation.

Other Materials Considered

The materials discussed in the following paragraphs are potential contaminants that were not placed on the master list of contaminants for the reasons previously discussed, but which warrant further discussion because they are mentioned in other source material as possible contaminants.

Unsymmetrical Dimethyl Hydrazine (UDMH)

UDMH was used in small amounts and stored for use in small sealed canisters. UDMH was carefully handled and controlled on NIKE sites. Spills very rarely occurred, and only intentional landfilling would present a contamination situation. In the environment, UDMH does not persist because of its reactivity. UDMH will not occur on NIKE sites, except in sealed canisters, and will not be found in water or soil samples.

Ethylene Oxide

Ethylene oxide was used throughout the NIKE program as a fuel for the Accessory Power Supply (APS) system. This system

burned ethylene oxide primarily to power missile guidance hydraulics. The system was tested periodically with a "hot run." Waste ethylene oxide was disposed of immediately by burning or dilution in water and on-site dumping.

Ethylene oxide is a reactive, volatile liquid stored at low temperatures. (It has a boiling point of 11 °C.) In the environment, it decays in a very short time. No ethylene oxide remained as a NIKE site contaminant.

Aniline and Furfuryl Alcohol

These starter fuels were not used in large quantities and pose very little contamination hazard.

JP-4

JP-4 is a hydrocarbon fuel similar to kerosene. Contamination by JP-4 is considered along with other fuels under the hydrocarbon category.

Low-Level Radiation

Radiation resulting from electrical tube disposal caused extremely minute contamination with no associated hazard. Leakage from nuclear weapons did not occur according to knowledgeable sources.

IRFNA (Nitric Acid)

IRFNA was an extremely hazardous material that was handled with extreme caution by NIKE site operators. Very little contamination via spillage occurred. The small amounts that were spilled rapidly reacted to become nitrates. Nitrates occur naturally in soils and are very commonly used as fertilizer. There is little chance that serious contamination of NIKE sites occurred as a result of the use of IRFNA.

Polychlorinated Biphenyls (PCBs)

PCBs were present on NIKE sites in permanent, sealed electric transformers. Small, random leaks of transformers may have occurred during site operation and after deactivation. Contamination resulting from PCBs would be small, localized, unpredictable and unlikely to be discovered except from visual observation of a leaking transformer. Therefore, PCBs were not included in the master list for screening during the Preliminary Determination Phase.

Asbestos

Asbestos may still remain on some sites in its original form in buildings, on piping and ductwork. It could potentially be removed if demolition occurs at the site. Asbestos was not included on the master list for screening during the Preliminary Determination Phase Investigations.

PHASE II PROGRAM

Phase II of the investigation involved field and analytical projects at 11 specific sites across the United States. Selection of the sites was intended to provide a broad look at NIKE sites in distinct geographic regions. Current ownership and use and relevant environmental considerations were factored into the selection process. Table 2 provides a general description of nine of the 11 sites investigated, each site's general geographic region of the United States, a brief description of the site and contaminants observed at the site. The reports of the investigations are under review by the USA Corps of Engineers and other government agencies, so specific locations cannot be provided at this time.

Table 2 Phase II NIKE Sites

SITE DESIGNATION	GEOGRAPHIC REGION	GENERAL DESCRIPTION	
L Site]	Southeast	Launchir Area - 23 sc., IFC Area - 8 sc., no undergraund siles, 3 above ground launch areas, used from 1959 to 3546, our enkly menned by constry school system, slight contimiration	Tetrachiare Lipiane (Perchiare Lipiane) in groundue te r
1. Bite 2	Nor these t	Launcher Area = 19 act., IPC Area = 9 ac., 3 underground éilee, used fram 1956 to 1967, extremily samed by eily actual system, no DOD contimina- tion evident.	MD DDD contaminetion evident
3 Site 3	Engt	Launcher Ares — 48 sc., IFC Ares — 6 sc., 3 underground slies, used from 1955 to 1961, our muly sound by Ossety restation dept., slight contamination	Bydraulic fluid in minaile dile
4 Sito 4	Central	Leurother Area - 14 ac., 1PC Area - 9 ec., 3 undergrand ollos, used from 1951 to 1979, our rently sand ty otata school rysim, continuetion in ground water, ourface water, sollo	Trichloraethano; 1,1,1- trichloroethano; 1,2- dichloraethano; viny1 ahloridu; toluono; chloridura; ethy1 Lonsano trana-1,2-dichloraethano
5 Bite 5	Jouth	Launcher Ares - 24 so., 1PC Ares - 11 ac., no underground silos, 3 absvegraand Launch Arcas, used from 1960 to 1964, carcrenity cannol by Riste achesi opsion no DDD contaminution evident.	Me DCD contenination evident
6. Site 6	North	Launcher Aran - 59 ac., IPC Aren - 21 ac., 6 underground allos, used from 1955 is 1970, our remuly annual by fily achool system, slight contamination	Diessi fusi in sciji neza undergroundi iuni
7. Aite 7	Hill Linetail	Launcher Aros — 17 ap., IPC Aros — 5 ac., 2 undergrand allos, used from 1860s 1866, our ently owned by county recreation dept., no DOD contamination evident.	Be DCD contentration erident
0. Bite ð	lanst	Laurcher Arun ~ 26 ac., IPC Arun ~ 18 an., 2 undergrand siles, used from 1933 to 1954, currently cancel by U.B. COR, wey slight contamination in grand wates and onli, typicoulis fluid in allas.	Law Levels of Lotra- dhioranthens; 1,1-di- dhioranthens; 1,1,1-tri- dhioranthens; hydrawlic fiuid.
9 Eite 9	Bouth	Launcher Aren - 24 ac., IFC Aren - 10 ac., no underground silen, 3 above ground launch arena; upad from 1944 to 1575; ourcestly anned by U.A. Refu Dept.; no DCD contamination evident.	ik DD centeriation evident

A typical site investigation included the following work elements:

- Preliminary site visit
- Preparation of site-specific work plans
- · Installation of groundwater monitoring wells
- Development of groundwater monitoring wells
- Sampling of groundwater monitoring wells, surface water and soils at the site
- Chemical and physical analysis of the water and soil samples
- Evaluation of the analytical data
- Preparation of engineering report, including a site hazard ranking system (HRS) report

The analytical program for each site included analysis for volatile organic compounds, hydrocarbons (diesel and gasoline), metals and nitrates. Results from the analyses were compared to applicable water quality standards and criteria and soil criteria to determine if contamination was present at the locations sampled.

Study Results

The following are generalized results and conclusions derived from the field investigation phase of the study:

• A general conclusion based on the 11 investigations would be that the majority of the NIKE sites most likely are not contaminating the environment except on a very localized basis. Contamination was only present at a few of the sites and generally at only a few of the sampling locations. Particular contamination discovered at the sites included volatile organic compounds near missile silos, diesel fuel near underground tanks and hydraulic fluid in missile silos.

• Contamination detected at the sites was located around operational structures such as the missile silos and near underground fuel tanks related to support units such as the generator building. However, the contamination appears to be related most often to inadequate or incomplete deactivation rather than operational practices. For example, an area near an underground tank showed visible surface contamination of diesel fuel. If the tank had been properly deactivated by filling, or removed during deactivation, the contamination probably would not have occurred. Likewise, hydraulic fluid was present in several missile silos, either floating on water present in the silos or in the silo sump. If the deactivation process had removed all the hydraulic fluid from the units, the contamination most likely would not have occurred.

From information developed in Phase I and Phase II of this investigation, it appears that contamination can occur at installations formerly used as NIKE batteries. However, contamination does not appear to be widespread at former NIKE sites and subsequent investigations should be centered around operational units such as the missile silos and at support units with underground fuel tanks. The most likely contaminants will include volatile organic compounds and hydrocarbons.

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Remedial Investigations and Emergency Response Measures at a Montana RCRA/CERCLA Site

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ABSTRACT

Extensive remedial investigations have been conducted at this northwestern Montana site where a wood treating plant operated from 1901 through July 1986. Wood preserving fluids have entered the groundwater, and areas of heavy soil contamination exist near former wastewater disposal areas. The site is adjacent to Flathead Lake, thus requiring a study of the waters and biota of the lake. The lake also serves as the municipal water supply for the study area. Emergency removal of contaminants which had accumulated in a pond near the lake was conducted to prevent washout of oily wastes.

Activities at the site are governed by two regulatory programs and by three regulatory agency groups. An administrative order on consent has been signed by Burlington Northern Railroad and the U.S. EPA to conduct a CERCLA remedial investigation and feasibility study (RI/FS) at the site, and RCRA Groundwater Quality Assessment and Closure Plans and issues exist. Both the state and U.S. EPA RCRA groups and the U.S. EPA Superfund group are involved in project oversight, review and approval.

INTRODUCTION

Burlington Northern Railroad has been conducting remedial investigations at this former tie treating plant in Somers, Montana, since 1984. These investigations have included installing and sampling 38 groundwater monitoring wells, drilling and sampling over 100 soil borings and test pits, sampling surface water and sediment, sampling drinking water from private wells and the municipal supply, sampling waste, analyzing fish tissue and conducting bioassays. Results have indicated that localized areas of contamination exist at the site within and adjacent to former wastewater management structures. The site contains RCRA-regulated units and has been proposed for inclusion on the National Priorities List.

During April 1985, the U.S. EPA declared that site conditions constituted an emergency and ordered the excavation and containment of contaminants present in a swampy area adjacent to Flathead Lake, the largest natural freshwater body west of the Mississippi. Within 1 month, two double-lined impoundments were constructed, over 3000 yd³ of soil and 100,000 gal of water were removed and a 500-ft rip-rap dike was constructed along the shoreline.

Additional site investigations currently are being conducted under CERCLA and under an RCRA Groundwater Quality Assessment Plan. The proposed closure of the RCRA facilities is under agency review, and CERCLA feasibility studies will be conducted.

PROJECT DESCRIPTION

Geologic Setting

The Somers Site (Fig. 1) is bounded on the south by Flathead Lake, on the west by a slough or former river channel as well as a federal waterfowl production area and on the east by a bedrock outcrop.



Figure 1 Burlington Northern Superfund Site and Surrounding Area— Somers, Montana

The site is located in northwestern Montana within the Flathead Valley. The mountain formations in the area are from the Late Cretaceous period and are composed of Pre-Cambrian sediments, primarily quartzite and limestone. The last glacial advance of the late Wisconsin age produced most of the lakes, drainages and moraines in the area. The Flathead arm of glacial Lake Missoula once covered the entire valley. The silts, sands and clays which were deposited within the glacial lake are now the subsurface soils of the study area.

Flathead Lake is the largest natural freshwater body west of the Mississippi with a maximum length of over 28 miles, a mean width of 6.5 miles and a coverage of over 117,900 acres. The mean depth of the lake is 44 ft, and the maximum depth is over 360 ft. The northwestern bay area near the site is relatively shallow and is a depositional area for sediments from Flathead River. Kerr Dam, constructed in 1938 and located at the natural outlet of the lake, regulates the upper 10 ft of the lake for power generation.

Site History

Wood treating operations have been conducted at this site since 1901. The site has been operated by Burlington Northern Railroad since 1971 and by its predecessors or others prior to that time. Wood preservatives used at this site were zinc chloride (1901 through 1939), chromated zinc chloride (1940 through 1943) and creosote/petroleum mixtures (1927 through 1986). Wastes generated at the Somers facility were comprised primarily of steam condensate from the steam lines used to heat the preservatives in the treatment process. Originally, a single condensate loop existed at the plant. Excessive downtime for boiler cleaning, however, required that two loops be piped to separate the contaminated stream from the uncontaminated stream. Condensate derived from space and tank heating was returned to to the boiler, while that derived from the retorts was disposed of as waste. Until 1971, this waste stream was discharged to an unlined lagoon immediately south of the retorts. The lagoon over-'flow discharged to an open ditch which drained to a swampy area adjacent to Flathead Lake. A pond formed along the ditch in these wetlands. The pond sediments were, in areas, essentially saturated with oils. The presence of the swamp pond and the old lagoon were the basis of the initial CERCLA investigations.

From 1971 to July 1984, wastes were discharged to a bentonite lined lagoon located northwest of the retort building. These waters were first passed into an oil water separator. The primary, lined lagoon overflowed to a second unlined lagoon. The lagoons were designed for total evaporation on an annual basis. These facilities are regulated under RCRA. In July 1984, a renovated condensate return system was installed at the site which recombined both condensate streams into one loop and eliminated all process wastewater discharges. Condensate from the retorts then passed through an oil sensor and, if necessary, was diverted away from the boiler to an evaporative reclamation system.

Other waste sources at the site were the drippage from freshly treated charges as they were pulled from the retorts and, to a lesser degree, the drippage from ties in storage. The vacuum applied to the charges prior to removing them from the retort minimized the amount of drippage. Charges were air dried in the drip area for 8 to 12 hr before being moved for loading or storage.

EMERGENCY RESPONSE ACTIONS

The long fetch of the Flathead Lake Valley causes strong winds, and winter storms along this lake can be especially violent. After the winter of 1984, shoreline erosion near the swamp pond was evident and the concern was raised that another major storm could engulf this pond and the contaminated sediments in it. Plans had been submitted by Burlington Northern Railroad to the Army Corps of Engineers and to county officials to erect an earthen dike which would contain the wastes in the pond in the event of a major storm.

Political difficulties arose with the permit at the time. The lake was beginning its spring rise. In April 1985, the U.S. EPA declared that the site conditions constituted an imminent and substantial endangerment and Burlington Northern entered into an administrative order on consent for the emergency removal and containment of the swamp contaminants.

Plans were developed to excavate the heavily contaminated sediments known to be present in, and adjacent to, the swamp pond, to backfill the excavated area with clean materials and to construct a rip-rap dike along the shoreline near the pond. Storage facilities were needed not only for these contaminated sediments, but also for the contaminated waters that were in and adjacent to these sediments.

A decision also was made to retrofit the existing RCRA lagoons at the plant site. The main RCRA lagoon still contained an undetermined amount of contaminated soils. The secondary or overflow RCRA lagoon was overgrown with vegetation. Use of a synthetic liner material, high density polyethylene (HDPE), was selected as the most appropriate means of retrofitting these lagoons.

Emergency response site activities began on May 1, 1985 with the construction of a work pad and roadway into the swamp area. On May 6, wastes and soils in the existing RCRA lagoons were excavated and temporarily stockpiled to prepare the lagoons for lining. Approximately 600 yd³ of sludges and stained soils were excavated from the main RCRA lagoon. The lining crew arrived on May 10 and began lining operations the following day. Twelve days later, over 170,000 ft² of 60 and 80 mil HDPE liner, drainage grid and filter fabric had been installed. One lagoon was constructed for the storage of contaminated soils and sediments, and its design included both a leachate collection system and a leak detection system. The other lagoon was constructed for water storage and included a leak detection system.

During the lining operations, a crew was simultaneously working in the swamp pond to pump and remove free water and to excavate and stockpile the contaminated sediments. The first loads of contaminated soils were placed in the lined lagoon on May 23, and the final loads were transported on June 1. Water was pumped from the excavation area continually.

Soil excavation limits were based on the macroscopic extent of contamination. Although appearance alone could be deceiving given the natural organic swamp soils in the area, the distinctive odor and staining characteristics of the creosote-contaminated soils were conclusive indicators. Samples of the excavated soils and water and of the soils left in place were collected for analysis of polynuclear aromatic hydrocarbons (PAH) and benzene extractable organics. On the basis of PAH analysis 96% removal was achieved while, in terms of benzene extractables, 86% removal was achieved. Upon completion of the waste excavation, a 500-ft rip-rap dike was constructed along the shoreline.

REMEDIAL INVESTIGATIONS

The remedial investigation work plan negotiated under the administrative order on consent calls for the following site investigations:

- Sampling and Hazardous Substance List (HSL) analysis of wastes, groundwater and surface water
- Installation of additional deep groundwater monitoring wells and quarterly groundwater sampling and analysis
- Surface and subsurface soil sampling and analysis
- Sediment sampling and analysis along Flathead Lake, the waterfowl production area and the slough
- Surface water sampling within Flathead Lake and the slough
- An evaluation of the potential impacts of air emissions from the plant
- Sampling and analysis of the municipal water supply and of private wells for PAH, down to the ng/l level
- Sampling and analysis of the tissue and viscera of fish collected within Flathead Lake
- Bioassay screenings of rainbow trout and water fleas using sediments collected from Flathead Lake
- Evaluation of the potential uptake of PAH by grasses along the former discharge ditch and the subsequent uptake of PAH by cattle grazing on those grasses

The U.S. EPA has since requested an amendment to that work plan to address the sampling and analysis of waterfowl food chain items (vegetation and benthic organisms) and, based on the results of food chain samples, potential sampling of the waterfowl.

Prior to issuing the consent order, wastes, groundwater, surface waters, private and municipal water supplies and surface and subsurface soil samples were collected and analyzed. The following summary of the data is derived primarily from these initial investigations.

Soil Contamination

There is evidence of soil contamination within the original dis-

posal lagoon, along the ditch which carried the lagoon overflow into the swamp, within the swamp along the former pond area, along the drip track, in subsurface beach sediments and in a localized portion of the slough. The old disposal lagoon actually contains deposits of white, crystallized naphthalene, and one sample from the lagoon contained a reported 50% naphthalene concentration. The majority of the contaminated soils along the ditch and in the swamp pond have been removed. Drip track contamination is restricted to the upper 1 ft or so of soils. Contaminated beach sediments exist near the former ditch and are located below 3 to 4 ft of clean sediments. One sediment sample from the slough has been reported to contain elevated levels of PAH and zinc. This sample was from an area used for black tie storage before construction of Kerr Dam raised water levels in 1938. An estimated 15,000 yr³ of contaminated soils remain at the site.

Groundwater Contamination

Groundwater at the site is an alluvial water table aquifer with no overlying confining layer present. Groundwater is relatively shallow, ranging from 15 ft below ground surface near the RCRA lagoons to less than 5 ft in the vicinity of the CERCLA lagoon and ditch; the swamp is a surface expression of groundwater.

Groundwater flows eastward toward the slough in the northern portions of the site and bends toward the lake as it moves south. The groundwater gradient in the swamp reverses with lake level changes. Bailer recovery tests indicate very low hydraulic conductivities in the range of 10^{-3} to 10^{-4} cm/sec for the upper fluvial sands, 10^{-4} to 10^{-5} cm/sec for the lower silts and silty sands, and 10^{-5} to 10^{-6} cm/sec in the clays, silts and sands within the swamp area.

Trace levels of PAH have been found in the groundwater throughout the site. Areas of heavy PAH contamination (greater than 5 μ g/l) are restricted to those areas that received direct wastewater discharges. Low molecular weight PAH, particularly naphthalene, dominate in all groundwater samples. Initial groundwater samples were analyzed for ng/l levels of PAH. Such analyses are now being conducted only on potable water supply samples for public health assessment purposes. The U.S. EPA criteria level for carcinogenic PAH is 28 ng/l at the 10⁻⁵ risk level. No potable samples from the study area have exceeded this risk level.

Air Contamination

Studies conducted on the potential impacts of air emissions, on the potential uptake of PAH by grasses and cattle, the analysis of fish tissue and the bioassays all resulted in findings of no significant impact. Air quality within the plant site was within permissible OSHA limits. A literature review of grass uptake demonstrated that no risk of cattle uptake existed. Fish tissue were free of detectable PAH. Bioassays found that the sediments collected from the near shore of Flathead Lake adjacent to the former swamp pond were non-toxic.

Biological Studies

Negotiations are currently underway on the need for further evaluation of the potential impact and uptake of PAH on waterfowl. The U.S. EPA has requested a plan to sample and analyze waterfowl food chain species and, if these results show a potential for impacts to waterfowl, to sample and analyze the waterfowl.

Issues to be resolved include a definition of "significant" concentrations in the food chain, the influence of the migratory nature of the waterfowl on any results, and general sampling and analytical procedures. No U.S. EPA-approved methods exist for waterfowl analysis, and significant time and money already have been spent at this site for verification of an analytical method other than a U.S. EPA-approved method, i.e., the work done to obtain U.S. EPA approval of the method used for ng/l level analysis of PAH in water.

RCRA/CERCLA INTERACTIONS

Project activities periodically shift in emphasis from CERCLA related investigations and negotiations to RCRA compliance issues and back again. A brief regulatory history of the site follows. The RCRA Part B permit application for the site was requested by the state of Montana in December 1983.

In February 1984, the state came to the site and collected soil samples along the old discharge ditch. Burlington Northern's response to concerns subsequently raised by both the State and U.S. EPA was quite fast tracked. An RI/FS Work Plan was submitted to the U.S. EPA in April 1984, and a Closure Work Plan was submitted to the state in May 1984.

The summer of 1984 was a period of intensive field investigations to characterize the site conditions and to determine the extent of contamination. The site was proposed for inclusion on the National Priorities List in October 1984. In November 1984, a status report and work plan for additional remedial investigations was submitted to both agencies. Additional discussions and meetings were held with the two agencies, and a RCRA Closure Plan was submitted to the state in April 1985.

Plans changed drastically with the issuance of the U.S. EPA's emergency response order and, rather than proceeding with closure of the RCRA lagoons, the lagoons were retrofitted to accept the wastes generated during cleanup of the swamp area. Negotiations then continued with the U.S. EPA on the proposed CERCLA remedial investigation work plan. An administrative order on consent to conduct the CERCLA RI/FS was signed in October 1985, and Work Plan approval was obtained from the U.S. EPA in March 1986.

In the fall of 1985, transportation of the wastes which had been excavated from the swamp and placed in the retrofitted RCRA impoundment began. These wastes were transported to another Burlington Northern RCRA facility in the state for storage and ultimate detoxification. In late September 1985, Burlington Northern was informed that these waste transfers would no longer be approved if the Somers facility lost interim status by not submitting a Part B permit application by Nov. 7, 1985.

A Part B permit application was then prepared and submitted to the state to allow these transfers to continue. Preliminary comments were received on the Part B from both the state and U.S. EPA RCRA personnel in March and April 1986. As transfer of the facility wastes was then complete, the Part B was withdrawn and revised Closure and Groundwater Assessment Plans were prepared and were submitted in August 1986.

Additional site investigations were conducted based on concerns raised during this preliminary RCRA Part B review. The question remains of whether or not these additional data can be incorporated into the CERCLA site assessment as the data were collected without an approved CERCLA Field Operations Plan.

Attempts to combine the two regulatory programs into one overall site programs have to date been unsuccessful. RCRA authority cannot be waived, and a CERCLA consent order has been signed and is in effect. Implementation of the Hazardous and Solid Waste Amendments and a recent decision by the U.S. EPA that RCRA sites will no longer be eligible for CERCLA consideration appears to have opened the option of placing the site solely under RCRA. This option is being evaluated at this time.

CONCLUSIONS

Investigations conducted at this former wood treating site in northwestern Montana have demonstrated a localized pattern of soil contamination and of heavy (greater than 5 μ g/l) groundwater contamination resulting from past wastewater disposal practices. This localization of the contamination is attributable in part to the low permeability of the site soils which consist of sands, silts and clays in a lacustrine environment. Investigations of other media including private wells, Flathead Lake which serves as the municipal water supply for the area, air, grasses and aquatic life have shown no adverse impact from site operations or past disposal practices. Additional investigations of waterfowl food chain species and of waterfowl themselves have been requested.

These investigations are being conducted under a CERCLA administrative order on consent and under a RCRA Groundwater Quality Assessment Plan. Plans for closure of the RCRA facility have been submitted, but RCRA groundwater corrective action and monitoring issues will remain along with CERCLA feasibility studies and corrective action issues. Currently, RCRA related investigations must be part of a U.S. EPA-approved CERCLA plan to be incorporated into the CERCLA investigation results.

An emergency response cleanup of contaminants within a swamp area adjacent to Flathead Lake was conducted. Within a one-month period, two double lined storage lagoons were constructed and over 3,000 yd³ of contaminated soils and over 100,000 gal of contaminated water were removed from the swamp. The area was backfilled with clean pit run gravel, and a 500-ft rip-rap dike was constructed along the shoreline.

ACKNOWLEDGEMENTS

The author wishes to acknowledge and thank Burlington Northern Railroad for their support and review of this paper. Data on the site conditions and on the extent and nature of contamination at the Somers site are from project reports generated by the following groups in addition to Remediation Technologies: Hydrometrics of Helena, Montana; ERT of Concord, Massachusetts and Ft. Collins, Colorado; and Soil Exploration Company of St. Paul, Minnesota.

A Third Party Neutral "Validates" an RI/FS

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ABSTRACT

The objective of this paper is to describe the role and impacts of a third party neutral validation of a Remedial Investigation and Feasibility Study. This paper is based on a case study. After describing the site and the generic approach to validation, the paper provides the current status of site activities and concludes with a discussion of the potential impacts of a third-party validation.

INTRODUCTION

A method to speed the cleanup of hazardous waste sites is being tried at a Northeastern site where a third party neutral is working with the state and the Potentially Responsible Party (PRP) to ensure that the Remedial Investigation/Feasibility Study (RI/FS) meets federal requirements.

The third party neutral, Clean Sites, Incorporated (CSI), is an independent non-profit organization formed 2 years ago to speed the cleanup of hazardous waste sites. CSI became involved at the site in June 1985 at the request of the sole PRP.

The PRP and the state had worked unsuccessfully for 2.5 years to negotiate an agreement for the PRP to conduct an RI/FS at the site. In January 1986, the PRP and the state's Department of Environmental Protection (DEP) signed a consent order under which the PRP would do a voluntary surface cleanup as well as an RI/FS. The order requires that the RI/FS be designed to assess surface and groundwater quality and identify any contamination not already discovered at the site during two previous studies.

The consent order specifically requires CSI to certify that all the work conducted in the RI/FS is consistent with the NCP, the regulatory framework for CERCLA, and other relevant guidance documents.

The site is not listed on the NPL. Therefore, the U.S. EPA did not enter into the consent order and the RI/FS is not legally required to be consistent with the NCP. In fact, the NCP does not allow the U.S. EPA to evaluate a cleanup study unless it is conducted under an agreement with the agency.

However, the PRP wanted the site's RI/FS to meet NCP requirements to assure the study's long-term viability in the event the site was placed on the NPL in the future. It saw CSI's validation of the site's RI/FS as a way of helping demonstrate to the U.S. EPA that the study was consistent with relevant guidances and regulations. The PRP also thought CSI's validation of the RI/FS would speed its approval, ultimately speeding the cleanup of the site.

In addition, the company wanted a credible, neutral, third party to assist in further negotiations. For one thing, the company thought that as a neutral facilitator, CSI could help give the state's Water Authority, which was intensely interested in, but not part of, the negotiations, an opportunity to be heard and responded to.

For the state, CSI's involvement offered the hope that the final product would require less time to review because it would not require extensive revision. For CSI, the project offered the first opportunity to use its Technical Review and Compliance division's expertise in chemistry, biology, hydrogeology and engineering to validate a site cleanup study.

SITE BACKGROUND AND REGULATORY HISTORY

Approximately 50% of the surface of the 102.8-acre site consists of five interconnected ponds which ultimately drain into a lake which is a drinking water supply source for the nearby city (Figure 1). Several industrial and private wells are located downgradient of the site and are possible groundwater receptors.

Around 1900, the PRP acquired a 200-acre parcel of land which included the site. Over the years, the site was used for a variety of purposes including the storage and disposal of inorganic and organic materials from its nearby plants and laboratories.

In response to a request from the state's DEP, the PRP submitted a report in 1981 on the contamination at the site. The company submitted a second phase of the report a year later.

From 1981 to 1982, during part of the period the state DEP and the PRP were negotiating for the PRP to conduct the RI/FS, the DEP sampled both on-site and off-site to define sources of contamination. In May, 1984, a U.S. EPA Field Investigation Team assessed the site for possible placement on the NPL.



VALIDATION—A PHASED PROCESS WITH SEVERAL SEPARATE REVIEWS

CSI realized that for a validation of the RI/FS to be meaningful, members of its validation team must give constant feedback to the contractor and responsible parties conducting and managing the RI/FS. If this were not the case, a PRP could find itself in the position of having expended as much as 2 years of manpower and expense in sampling and analytical work only to find that more sampling or even a second RI/FS was required to address those points that were not correctly or satisfactorily addressed in the first study. Thus, CSI developed a "phased validation" process which called for CSI to review the contractor's work at several specific points throughout preparation of the RI/FS. This would guarantee high quality end results.

The CSI site R1/FS validation process, therefore, was divided into five, or potentially six, phases. CSI would validate the:

- R1/FS Work Plan which includes site background and the site sampling plan
- Site Operations Plan (SOP) which includes the Worker Health and Safety Plan and the Quality Assurance Project Plan for the site
- Endangerment Assessment which assesses the potential health and environmental threats of the site before and after potential remediation
- Initial screening of alternatives for remediation
- Draft R1/FS which includes a detailed analysis of remediation alternatives
- Recommended option and conceptual design for cleanup, if requested by the state and the PRP

CSI's staff members validate RI/FS with the assistance and guidance of CSI's Technical Advisory Board. The seven-member board is chaired by Dr. Morton Corn, of the Johns Hopkins School of Hygiene and Public Health. Members include experts in hydrogeology, environmental engineering, toxicology, public health, bioengineering and chemical engineering.

Validation of each phase proceeds in a prescribed manner (Figure 2). Upon receiving documentation for any of the above phases, members of the CSI validation team review the documents and send their comments to members of the Technical Advisory Board subcommittee assigned to the site. They also review the documents and may revise comments by CSI's staff members. The validation team then passes the revised comments on to the PRPs and their contractors.

Shortly after all of CSI's comments have been discussed and, if necessary, acted upon by the contractor, CSI sends a formal validation letter for that phase of the RI/FS to both the PRP and the regulatory agencies involved. The letter describes the extent to which CSI's comments have been addressed and provides CSI's formal position as to whether or not that phase of the RI/FS is consistent with EPA regulations and guidance.



Validation of RI/FS

Figure 2 Institutional Relationships in the Validation Process

STATUS OF THE RI/FS VALIDATION EFFORT

As of August 1986, CSI had validated the first two phases of the RI/FS, the Work Plan and the Site Operations Plan. The state's DEP approved the Work Plan with some modifications and is planning to review the Site Operations Plan.

Members of CSI's Technical Advisory Board subcommittee for the project who have visited the site and commented on the RI/FS are Dr. John Cherry, professor and chairman of the Institute for Groundwater Research at the University of Waterloo, Ontario, Canada and Kenneth Biglane, environmental consultant and former director of hazardous response support at the U.S. EPA. Dr. Bernard Goldstein, professor and chairman, Department of Environmental and Community Medicine, Rutgers Medical School, is also a member of the subcommittee and has commented on the RI/FS.

Review of the Work Plan

In reviewing the Work Plan, CSI's key concern was to ensure that the primary hypothesis of the RI/FS (that the entire site was in a groundwater recharge zone and therefore contamination would eventually enter the pond) could be tested. CSI, therefore, recommended the addition of an additional sampling well cluster to prove or disprove the hypothesis (Figure 3).

CS1 also recommended adding cost estimates as part of the preliminary screening of remedial alternatives, as well as a list of applicable or relevant standards for the major contaminants.

In the absence of field sampling and screening techniques, CSI also recommended that at least one sample from each major area in each medium at the site be screened for the entire Hazardous Substance List.

CSI also recommended that the laboratory selected to conduct the various analyses meet the U.S. EPA's Contract Laboratory Program criteria.

Technical points made by CSI in its Phase I validation letter included some comments and information which the PRP did not approve. However, in order to maintain its neutrality, CSI is not obligated to have its correspondence reviewed in advance. CSI's validation of the Work Plan was made contingent upon adoption of the items which its technical staff recommended.



Figure 3 Hydrogeology of the Site Showing Possible Groundwater Recharge to Ponds and Lake

Review of the Site Operations Plan

CSI recommended that in the Site Operations Plan the data quality objectives be modified to reflect data usage, field sampling techniques be used where possible for screening and the sampling plan be changed to maintain consistency with the latest U.S. EPA CLP guidelines.

Schedule for Completing the RI/FS and Validation

Soil sampling and preliminary hydrogeological investigations at the site should be completed in the fall of 1986. Both rounds of groundwater, surface water sediment and urban drainage sampling are scheduled to be conducted from October 1986 to July 1987. The draft endangerment assessment is scheduled for completion in September 1987, and the initial screening of alternatives is scheduled for early November 1987. The draft RI/FS is expected in early February 1988, and the final report is due by early March 1988. All of these dates are contingent upon timely review and approval of the documents by all participating parties.

BENEFITS OF VALIDATION

Validating the RI/FS appeared to help break an impasse in negotiations between the PRP and the state over the PRP conducting the RI/FS. Those negotiations had lasted almost 2.5 years. A number of draft agreements had been exchanged, but no agreement had been reached.

Another benefit of having assistance from a third party neutral was that CSI's reviews acted as a built-in quality assurance/quality control procedure. Site visits by CSI technical advisory board and technical staff gave new and important perspectives to the problem and/or proposed solutions.

In the short run, having another party in the approval loop for a phased FI/FS lengthened the process. However, in the long run, in terms of gaining the state's approval and in guaranteeing a more effective RI/FS, it is hoped that CSI participation will actually shorten the process.

CONCLUSION

The important technical issues in hazardous waste site cleanups

are not black and white. Diverse disciplines such as hydrogeology, toxicology, microbiology, fate and transport modeling, analytic chemistry and economics all must be considered to effect a satisfactory cleanup. A third party neutral can examine these issues and offer impartial judgments.

Further, a third party neutral can help reconcile the potentially conflicting views presented as local, state and federal agencies attempt to fashion a site cleanup. PRPs traditionally have not been effective in establishing a nonadversarial dialogue with local community action organizations.

Some persons, however, question whether an additional viewpoint injected into a complex technical/political issue is an advantage. This concern is reduced in direct proportion to the technical competence and public accountability of the third party. Above all, the third party must be perceived as neutral by all involved parties.

The experience to date at this site proves that CSI can maintain neutrality in examining an RI/FS. While only time will tell, the participating parties believe that the result at this site will be a cleanup program that is environmentally acceptable and economically achievable.

Remedial Investigation/Feasibility Study, NOVACO Industries, Michigan

Mary Elaine Gustafson U.S. Environmental Protection Agency Chicago, Illinois Stephen J. Hahn CH2M HILL Bellevue, Washington

ABSTRACT

A Remedial Investigation/Feasibility Study (R1/FS) was conducted at the NOVACO Industries site in southeastern Michigan in response to a 1979 chromic acid tank leak. The leak contaminated groundwater in a shallow aquifer with chromium, forming a plume that currently occupies approximately 1 acre. An endangerment assessment of the site concluded that remedial actions are necessary to prevent the contamination of residential wells in the area by plume movement or leakage into a deeper aquifer from which individual residential wells draw water.

The RI/FS study evaluated two remedial action alternatives that would clean up the shallow aquifer using extraction wells as well as a "no action" alternative and an alternative water supply. The selected remedial action alternative consists of groundwater extraction and on-site treatment of contaminated groundwater using an electrochemical cell (primary treatment) and an anion exchange process (polishing treatment). The treatment plant is expected to remove trivalent and hexavalent chromium to below their respective NPDES permit limits, allowing the treated groundwater to be discharged to a nearby stream.

INTRODUCTION

In accordance with the National Contingency Plan (NCP), an RI/FS was conducted at the NOVACO Industries site to identify the lowest-cost remedial action alternative that protects the public health and welfare and the environment. Aspects of the study requiring special attention were a complex hydrogeologic setting, strict groundwater cleanup criteria and discharge standards requiring a high level of treatment.





Site Location and Description

NOVACO Industries is located in southeastern Michigan, approximately 50 mi south of Detroit. The site occupies a 2.6 acre parcel and is bordered on the north, east and south by residential areas and on the west by the Veterans of Foreign Wars (VFW) Post 9656 (Fig. 1).

The geologic profile at the site consists of about 25 ft of glacial outwash (sands and gravels) with low to moderate hydraulic conductivity overlying limestone bedrock. The upper surface of the limestone is weathered, creating a 5-ft thick zone of moderate to high hydraulic conductivity. Beneath the weathered limestone, there is a thick zone of competent limestone with hydraulic conductivities ranging from very low to very high, depending on the presence of fractures and solution channels in the limestone.

Groundwater in the sand and gravel/weather limestone zone is perched on the upper surface of the competent limestone. Groundwater occurs at a lower level in the competent limestone; thus, there is a potential for downward leakage from the sand and gravel/weathered limestone aquifer into the competent limestone aquifer. Groundwater flows horizontally in both aquifers toward the northwest.

There are approximately 85 single-family residences located within one-half mile of the site. In the downgradient groundwater flow direction and within 1,000 ft of NOVACO Industries, there are seven residences plus the VFW Post. All of these residences use individual water supply wells installed in the sand and gravel/ weathered limestone aquifer, in the competent limestone aquifer or screened across both aquifers.

Site History

A below-grade plating tank located within the NOVACO Industries building leaked an unknown quantity of hexavalent chromium into the groundwater on or before June 13, 1979. Within 24 hr following NOVACO Industries' detection of the leak, hexavalent chromium was discovered in NOVACO Industries' 20-ft deep well and in the VFW Post's 45-ft deep well. NOVACO Industries' well is screened in the sand and gravel/ weathered limestone aquifer, and the VFW Post's well is screened in both the sand and gravel/weathered limestone and in the competent limestone aquifer.

A groundwater extraction and treatment program was undertaken by NOVACO Industries from July to November 1979. In addition, NOVACO Industries replaced the contaminated wells with deeper wells installed in the competent limestone aquifer. Approximately 122,000 gal of contaminated groundwater were extracted, treated on-site and discharged into a roadside ditch. The extraction and treatment program was discontinued by NOVACO Industries before all the hexavalent chromium had been extracted from the aquifers. From 1979 to 1981, the Michigan Department of Natural Resources (MDNR) and the Monroe County Health Department (MCHD) monitored the groundwater. Hexavalent chromium concentrations in the contaminated wells declined; however, a residential well located west of the VFW Post was contaminated. Like the contaminated VFW Post well, this residential well also is screened in both aquifers and was replaced by a deeper well installed in the competent limestone aquifer. Maximum hexavalent chromium concentrations were measured in the NOVACO Industries well at 940,000 μ g/l. The U.S. EPA primary drinking water standard for total chromium is 50 μ g/l.

NOVACO Industries was placed on the National Priorities List (NPL) in September 1983, and the U.S. EPA conducted remedial investigations at the site in 1984 and 1985. A feasibility study was initiated in 1985 and completed in 1986,¹ and a Record of Decision was signed by the U.S. EPA on June 27, 1986.²

REMEDIAL INVESTIGATIONS

Remedial investigations consisted of an electromagnetic survey, monitoring well construction, aquifer testing and sampling and analysis of subsurface soils, groundwater, surface water and sediments. Sixteen monitoring wells were installed in three drilling phases, and groundwater samples were taken on four occasions between April 1984 and September 1985.

The significant conclusions of the remedial investigation were as follows:

- An approximately 1-acre plume of chromium-contaminated groundwater is present in the sand and gravel/weathered limestone aquifer with the horizontal limits indicated on Fig. 1. The apparent center of the plume is located 200 ft west of the underground tank that leaked.
- Maximum chromium concentrations within the plume were measured in the VFW Post's abandoned well in December 1984. These maximum concentrations were $3,220 \ \mu g/l$ and $2,780 \ \mu g/l$ for total chromium and hexavalent chromium, respectively.
- The plume appears to be vertically contained within the sand and gravel/weathered limestone aquifer; no monitoring wells or residential wells screened in only the competent limestone aquifer are contaminated.
- The piezometric water level in the competent limestone aquifer is approximately 20 ft lower than the phreatic water level in the sand and gravel/weathered limestone aquifer, indicating that there is a strong potential for leakage from the contaminated sand and gravel/weathered limestone aquifer downward into the uncontaminated competent limestone aquifer.
- Potential pathways for downward leakage between the two aquifers are limestone fractures, solution channels and improperly sealed well casings—all of which are probably present within the immediate vicinity of the contaminated groundwater plume.
- Based on measured hydraulic gradients and conductivities within the sand and gravel/weathered limestone aquifer, the maximum expected plume migration rate is 40 to 50 ft/yr to-ward the northwest.
- Chromium concentrations within the plume appear to be declining, as shown in Fig. 2. From 1980 to 1986, the rate of decline was approximately one log cycle every 3 years. By projecting this trend into the future and applying a safety factor of 1.5 to 2.5, it is estimated that detectable concentrations of chromium will remain in the plume for the next 13 to 18 yr.
- Declining chromium concentrations within the plume can be explained by attenuation and dilution processes. However, the remedial investigations did not include any groundwater modeling to attempt to quantify these processes.



Figure 2 Projected Chromium Concentration Decrease

ENDANGERMENT ASSESSMENT

Table 1 presents the applicable or relevant requirements, standards and other criteria for chromium. The major human health hazard from chromium-contaminated water is through ingestion. A "worst-case" exposure calculation would assume consumption of the maximum total chromium concentration measured during the remedial investigation—3,220 $\mu g/l$. This concentration exceeds the federal primary drinking water standard, the proposed recommended maximum concentration limit and all of the U.S. EPA health advisories.

The maximum hexavalent chromium concentration measured, 2,780 μ g/l, exceeds the U.S. EPA water quality criteria. Also, the calculated daily intake of hexavalent chromium, 5.560 μ g/l, is greater than the U.S. EPA acceptable chronic intake of 350 μ g/l for a 70-kg person.

IDENTIFICATION OF ALTERNATIVES

The feasibility study (FS) identified several remedial action alternatives based on site-specific goals and in accordance with the NCP. The alternatives were then screened for technical feasibility, environmental and public health impacts and costs. After this initial screening, the following alternatives were retained for detailed evaluation.

- No action
- · Groundwater monitoring and alternative water supply
- Groundwater extraction with on-site treatment and discharge
- Groundwater extraction with off-site disposal

AQUIFER CLEANUP CRITERIA

The federal drinking water standard for total chromium is $50 \mu g/l$. The State of Michigan is authorized to require cleanup to the background or non-detection level of $5 \mu g/l$, and the additional cost to pump to this level is small compared to the initial cost of cleaning to $50 \mu g/l$. Considering these criteria, and considering that currently available groundwater models, site data and related experience with similar groundwater extraction systems at other sites do not allow accurate prediction of chromium concentrations remaining in the aquifer versus gallons of groundwater extracted, the aquifer cleanup level that was pro-

	Table 1		
Applicable or Relevant and Appropriate	Requirements and	Other Criteria fo	or Cbromium

Contaminant	Pederal Primary Drinking	Proposed Recommended Maximum	Proposed scommended USEPA Water Quality Criteria Maximum (Ug/L)			USEPA Mealth Advisory ^C (Mg/L)					Acceptable
	Water Standard (yg/L)	Water Contaminant Standard Level (µg/L) (µg/L)	Pres Aqui 4-day	tic ^B <u>1-hour</u>	Human Health Water Only ⁰	l-day 10 kg Body Wt.	10-day 10 kg Body Wt.	Longe 10 kg Body Wt.	70 kg Body Wt.	Lifetime 70 kg Body Wt.	Chronic Intake (yg/day)
Total Chromium	50	120	N V	MV.	WV	1,400	1,400	240	840	170	N V
Trivalent Chromium	NB		541 ^d	4,540 ⁰	179,000						105,000
Hexavalent Chromium	¥2		11	16	50						350

a Source: Federal Register 30, 46936.

b Source: Federal Register 50, 30784. Criteria are for the protection of freshwater aquatic life and represent the maximum value not to be exceeded more than once every 3 yr on the average

c Source: U.S. EPA, Superfund Public Health Evaluation Manual, Draft, Dec 18, 1985

d Criterion dependent on water hardness according to the equation: e (0.8190 [1n (hardness)] + 1.561) At a hardness of 323 mg/l CaCO3, the criterion is 541 mg/l.

e Criterion dependent on water hardness according to the equation: e (0 8190 [1n (hardness)] + 3 688) At a hardness of 323 mg/l CaCO3, the criterion is 4,540 µg/l.

posed for Alternatives 3 and 4 involved a series of milestones as described below:

- Milestone No. 1: The extraction well system would operate until 50 μg/l (or lower) total dissolved chromium is achieved in every monitoring well and extraction well.
- Milestone No. 2: The extraction well system would operate to remove a second volume of groundwater equal to the volume of groundwater removed to achieve Milestone No. 1, or until non-detectable total chromium concentrations (5 μ g/l) are achieved in every monitoring well and extraction well, whichever comes first.
- Milestone No. 3: The extraction well system would operate for an additional period of time depending on the performance of the extraction well system in achieving Milestone No. 1 and 2. The U.S. EPA and MDNR will participate in the decision to continue pumping.

DESCRIPTION OF ALTERNATIVES

Alternative 1, no action, would not require any work at the site. Alternative 2 would monitor the groundwater and provide an alternative water supply (private wells or a public well system) to any residents whose wells become contaminated. These alternatives would not remove the chromium from the aquifer, nor would they remove the potential for migration of contaminated groundwater into the lower competent limestone aquifer.

Alternatives 3 and 4 would extract contaminated groundwater to below drinking water standards using a network of extraction wells, following the milestone approach. A groundwater model indicated six wells would be needed near the center of the plume to create a drawdown of at least 2.5 ft near the edge of the plume. Approximately 36,000,000 gal of contaminated groundwater would be pumped and treated over a 3- to 4-yr period to achieve Milestone 2.

In Alternative 3, a treatment plant would be constructed onsite. The treatment process would include electrochemical reduction, precipitation, filtration and ion exchange polishing units. The treated water would be discharged by a one-quarter long pipeline to nearby Indian Creek which flows into Lake Erie. In Alternative 4, the extracted contaminated groundwater would be disposed of in the South Monroe County Wastewater Treatment Plant by way of a one-mile-long pipeline.

EVALUATION OF ALTERNATIVES

Each of the above alternatives was evaluated on the basis of seven criteria. The results of this evaluation are shown in Table 2 and discussed below.

Public Health

Based on the endangerment assessment results, Alternative 1 would not protect public health and the environment. Although Alternative 2 would provide an alternative water supply, it would not remove the potential threat of the contaminated water migrating into the competent limestone aquifer. Alternative 3 and 4, on the other hand, would remove the contamination and the potential threat and would provide adequate protection to public health and the environment.

Costs

Capital, O&M and present worth costs for each alternative are presented in Table 3. Capital costs consist of direct and indirect costs which are summarized in Table 4. Groundwater monitoring,

Table 2 Summary of Detailed Evaluation

	Alternative	Alternative 	Alternative }	Alternative
Juchne logice Included				
Alternative vater supply-mov private/public voll	K A	P	AM	84
Groundestor extraction	RA.	RA	P	7
Quaite groundwater treatment	114	MA.	P	KA
Offaile grundwatar disposal (untrusted voter)	EA.	K).	HA.	,
Groundwater smallering	KA.	7	,	,
Performance (Dffect (veness)				
Prevents desper to public health from contamination of dewegradiant wells in sand/gravel againer		,	•	,
Prevents desper to public health from potential contemination of wells in the linestene agaifer		0	,	,
Groundwater extraction provents contexinated presedenter from mi- grating outside the innew estant of the total chronium plane	-	84	,	,
Obsite treatment renovue chronium to bolow federal and state standards	R).	24	•	K A
Beliebility (Descentrated Per- formation and Colf Meguirements)				
New public well/private wells are a proven technology	MA	,	EA.	MA
Groundwater entraction walls are a proven technology	24.4	24	,	,
Choite treatment by electrochemi- cal reduction/ion enchange polish- ing is a proven technology	RA.	**	,	M
A sever is a proven tachnology	84	MA.	MA	P
Lew OIL costs	RA.	7	0	0
Implementability (Constructibility and Time)				
One construction ensurem	MA	0	0	0
Basily installed with conventional equipment	MA.	,	ŀ	,

	Alternative	Alternative	Alternative	Alternative
Safety (During Construction)				
Acquires protection of workers	NA	0	0	0
Public Health and Environmental Considerations				
Jotantial for adverse impacts to human bealth from anyosure to movely contaminated wells in the gand/gravel aquifer	¥	7	7	,
Potential for adverse impacts to human health from exposure to newly contaminated wells in lime- stone aquifer	¥	o	,	,
Institutional Considerations				
Nets USEPA Groundwater Protection Strategy	м	¥	P	P
Probably meets MDP2S permit requirements for Indian Creek	NA	NA	P	MA
Neets pretreatment requirement for disposal at South Honroe County WMTP	MA	MA	NA	N
Cost				
Capital cost (\$1,000's)	0	5	560	264
Present worth (\$1,000's)	0	97	687	433

Note:

NA - Not applicable

P - Positive aspect

N - Negative aspect

0 - Neutral (neither positive nor negative) aspect

groundwater extraction, on-site treatment, well abandonment and off-site disposal are the primary operation and maintenance expenses. Table 5 presents the annual operation and maintenance costs based on a design flowrate of 50 gal/min. The 30-yr present worth cost is based on a discount rate of 10% and ignores inflation rates and salvage values.

Table 3 Cost Summary

-	Alternative	Capital Costs	OGM (total_cost/duration)	Present Worth
1.	No Action	-0-	-0-	-0-
2.	Groundwater Moni- toring and Alterna- tive Water Supply	\$5,000	\$112,000/20 yrs	\$97,000
3.	Groundwater Extrac- tion to below Drinking Water Standards with On- site Treatment and Disposal	\$560,000	\$419,000/6 yrs	\$887,000
4.	Groundwater Extrac- tion to below Drinking Water Standards with Off- site Disposal	\$264,000	\$183,000/6 yrs	\$433,000

•	Tal	ble 4	
Summary	of	Capital	Costs

	Estimated	Capital Costs	(\$1,000's)	
	Alternative	Alternative 3	Alternative	
General Requirements	0.2	23	11	
Abandon Monitoring Wells	3.0	3	Э	
Groundwater Extraction System	0	38	38	
Onsite Treatment System	0	288	0	
Sanitary Sewer (Pipeline)	$\frac{0}{1}$	0 352	$\frac{114}{166}$	
Construction Contingency @ 25% Construction Total	0.8 4.0	88 440	42 208	
Construction Engineering Cost 0 6% Total Implementation Cost	0.2	26 466	$\frac{12}{220}$	
Engineering Design Cost @ 10%	0.4	47	22	
Other Costs @ 10%	0.4	47	22	
Total Implementation Plus Engineering Cost	5.0	560	264	

Onsite Treatment (All	ernative 3)	
Labor	\$48,000	
Material	6,000	
Sludge Disposal ^a	3,000	
Power	7,000	
Backwash Disposal	16,000	
	\$80,000	
Groundwater Extractio	n (Alternatives 3 and 4)	
Monitoring (seven poi	nts) \$6,000	
Power	1,000	
	\$7,000	
Offsite Disposal (Alt	ernative 4)	
	\$21,000	
Groundwater Monitorin	g (Alternatives 2, 3 and 4	<u>1)</u>
	\$ 8,000	
Abandon Monitoring We	115	
	\$15,000 ^b	

a Sludge assumed to be hazardous and would require special handling and off-site disposal.
b After 20 yrs for Alternative 2 and after 6 yrs for Alternatives 3 and 4

Note: Annual O&M costs are based on 50 gal/min flow, 24 hr/day, 365 day/yr

Performance, Implementability and Reliability

Alternative 1 was not evaluated because there would be no construction involved. Alternative 2 would provide an alternative water supply (e.g., replacement wells) to affected residences. Replacement wells could be installed in less than 1 wk per well using proven, reliable well drilling techniques.

For Alternatives 3 and 4, extraction wells and a treatment plant or sewer could be installed in less than 6 mo. The groundwater extraction wells described for Alternatives 3 and 4 are used commonly at hazardous waste sites. The treatment plant in Alternative 3 is expected to remove hexavalent chromium to below detection levels. The installation of a sewer in Alternative 4 is also a proven technology. All three alternatives would require groundwater monitoring.

Safety

Protection of workers is not expected to be a problem in any of the alternatives. Level D protection for construction workers would be required for Alternatives 3 and 4 because extraction wells would be drilled within the limits of the plume.

Consistency with Environmental Laws

Several federal and state laws and policies apply to the technical evaluation of the alternatives for NOVACO Industries. RCRA is relevant because it identifies maximum concentrations for constituents in the groundwater. The maximum concentration for chromium under RCRA is 50 mg/l, which is also the drinking water standard. The Groundwater Protection Strategy (GWPS) identifies groundwater quality to be achieved during remedial actions based on aquifer characteristics and use. At NOVACO Industries, the GWPS would require cleanup subject to current RCRA policy.

The Michigan Environmental Protection Act 127 is a general act stating that no one shall pollute, impair, destroy or otherwise cause harm to the environment. The MDNR may conclude that the NOVACO Industries study area violates this act because the groundwater is contaminated.

The Water Resources Commission Act 245 authorized the adoption of water quality standards to be met in all state waters (including groundwater). The water quality standard to be maintained in groundwater is based on a policy of "nondegradation." Degradation is defined as a change in groundwater quality from local background conditions. Under the authority of the Water Resources Commission Act, the MDNR could determine that the groundwater at the site does not meet the requirements of the act and require cleanup to background levels.

Alternatives 1 and 2 would not be in compliance with the concentration limits under RCRA, nor would they be in compliance with the GWPS. Alternatives 1 and 2 also could be in violation of Acts 127 and 245.

Alternatives 3 and 4 would be in compliance with RCRA and GWPS. Both alternatives would be required to comply with Act 127 and Act 245. Discharge into Indian Creek in Alternative 3 would be regulated by the MDNR through compliance with the NPDES permit requirements and by federal ambient water quality criteria. The extracted groundwater under Alternative 4 would be discharged by a force main and existing sewer to the South Monroe County Wastewater Treatment Plant. All discharge to the sewer system is required to meet the pretreatment standards established by the Monroe Metropolitan Water Pollution Control System. Alternative 4 discharges would be in violation of these standards.

ALTERNATIVE SELECTION PROCESS

The major health concern associated with both Alternatives 1 and 2 is that hexavalent chromium might migrate downward from the upper sand and gravel aquifer into the competent limestone aquifer. Currently, the lower aquifer contains no detectable chromium. Most residential wells in the vicinity of NOVACO Industries draw from the lower aquifer.

Additional potential impacts of Alternatives 1 and 2 are that surface water quality and aquatic life may be adversely affected if contaminated groundwater migrates into Indian Creek, and that restrictions may need to be placed on the locations of future residential wells. Also, Alternatives 1 and 2 would not meet applicable federal and state regulations, including RCRA, the U.S. EPA GWPS, Michigan Environmental Protection Act 127 and the Michigan Water Resources Commission Act 245. For these reasons, Alternatives 1 and 2 were eliminated.

Alternatives 3 and 4 would clean up the upper aquifer by extracting groundwater and then either treating the extracted groundwater on-site with discharge to Indian Creek (Alternative 3) or disposing of the untreated extracted groundwater to the South Monroe County Wastewater Treatment Plant (Alternative 4). The time required for either alternative to clean up the aquifer is estimated at 3 to 4 yr.

Both alternatives would remove chromium from the ground-

water and achieve the same level of cleanup within the same time frame. Alternatives 3 and 4 also provide the treatment and disposal of extracted groundwater using technologies that are reliable and protective of public health and the environment.

Alternative 4 has a disadvantage; the initial maximum expected discharge concentration for hexavalent chromium exceeds the treatment plant's pretreatment standard (i.e., a discharge concentration of 800 μ g/l versus 5 μ g/l allowable). Furthermore, the treatment plant officials have stated objections to receiving extracted groundwater from the NOVACO Industries site because the additional chromium waste load might adversely impact South Monroe County's current practice of disposing of its sludge on croplands.

The Feasibility Study and the Record of Decision recommended Alternative 3 for remedial action because it is the lowest cost alternative that is technologically feasible and reliable and that effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare or the environment.

CONCLUSIONS

The RI showed that remedial action is needed at the NOVACO Industries site to protect public health and the environment from chromium-contaminated groundwater. The FS considered several technologies and alternatives that were cost-effective and technically feasible. The selected alternative would provide several benefits, including:

- Removal of chromium contamination in the sand and gravel/ weathered limestone aquifer, thus protecting the lower competent limestone aquifer
- Cleanup time of approximately 4 yr
- Elimination of the potential for public ingestion of contaminated groundwater
- Elimination of the need to place restrictions on future well construction
- Compliance with applicable federal, state and local regulations including RCRA, the U.S. EPA GWPS, Water Resources Commission Act 245, Michigan Environmental Protection Act 127, NPDES permit and ambient water quality criteria.

REFERENCES

- CH2M HILL, "Revised Public Comment Draft Feasibility Study Report, NOVACO Industries, Temperence, Michigan," April 11, 1986.
- 2. U.S. EPA, "Record of Decision," June 27, 1986.

The Soil Chemistry of Hazardous Materials: Basic Concepts and Principles

James Dragun, Ph.D. E.C. Jordan Co. Southfield, Michigan

INTRODUCTION

Increasing technological use of chemicals is one measure of society's advancement. However, as chemical usage has increased, society's and the environment's exposure to chemicals has increased, and a justifiable concern regarding the discovery of chemicals in our air, surface water, groundwater and soil has grown.

This seminar addresses only one aspect of the presence of chemicals in the environment: chemicals in soil and groundwater. The overall purpose of this seminar is to dispel a commonly held notion that soil is an inert medium that does not play a significant role in governing the behavior of chemicals. Soils are highly reactive systems that govern the concentrations of chemicals in groundwater. One must possess an understanding of the basic principles of soil chemistry in order to understand how soils govern the concentrations of chemicals in groundwater. In addition, it is most important to recognize that soil chemistry principles govern the success or failure of soil and groundwater treatment technologies as well as the performance and failure of TSD facilities.

SOIL AS A THREE-PHASE SYSTEM

Soil Chemistry can be defined as the study of the behavior of soil as a complex chemical and the study of the behavior of chemicals in soil. In order to properly characterize the soil system, the soil chemist draws information from numerous fields including colloid chemistry, geochemistry, organometallic chemistry, radiochemistry, analytical chemistry, geology, clay and soil mineralogy, soil genesis, soil fertility, soil microbiology, soil physics, fluid mechanics and hydrology.

The soil chemist views soil as a three-phase system—solid, liquid and air—in which numerous physical, chemical and microbial reactions occur simultaneously. It is not possible to describe, let alone discuss, all of the potential reactions that can occur within these three phases. However, this seminar will discuss in some detail several common misconceptions about the nature and extent of these reactions. Also, it will address several common misapplications of basic soil chemistry principles.

SOIL ORGANIC MATTER

The size of the organic phase of soil can range anywhere from 1 to 8% by weight for topsoil to generally less than 0.4% for subsoil. In other words, topsoil can contain as much as 80,000 ppm total organics; subsoil, as much as 4000 ppm total organics. Naturally occurring organic phases are comprised of fats, waxes, resins, carbohydrates, proteins, humified organic matter and other classes of organics such as:

alkanes alkanioc acids alkanols alkyl alkanoates alkyl benzenes alkyl methanoates alkyl n aphthalenes alkyl phenanthrenes methyl alkanones phthalates polynuclear aromatic hydrocarbons

The occurrence and concentrations of naturally occurring organic chemicals within these groups such as benzene, toluene, xylenes and ethylbenzene will be discussed during the seminar.

The organic phase of soil serves as the primary food preserve for numerous microorganisms which are responsible for the degradation of organic chemicals that enter into soil-groundwater systems. The average number of microorganisms found in soils can be extremely large. For example, the typical agricultural topsoil contains about 100,000,000 bacteria/gram of soil. Under optimum conditions, the number of bacteria could exceed 10,000,000,000/gram.

Each microorganism contains within its cell membrane literally thousands of enzymes which are responsible for performing over 36 "type" reactions. During the seminar, the type reactions responsible for the degradation of alkanes, aromatics and chlorinated solvents such as PCE, TCE, DCE, DCA, vinyl chloride, carbon tetrachloride and chloroform will be discussed.

SOIL MINERALS

The inorganic phase of soil is comprised of numerous soil minerals. Minerals react with both inorganic and organic chemicals that enter soil-groundwater systems. With regard to the former, soil minerals can immobilize metals through "fixation" reactions. Fixation reactions include the formation of chemical bonds with mineral surfaces (chemisorption), the irreversible penetration of mineral structures (solid state diffusion) and the precipitation of new soil minerals such as oxides, hydroxides, oxihydroxides and phosphates. This seminar will address the nature and extent over many different soil types of the fixation of at least one metal.

With regard to mineral reactions with soil minerals, it is most important to recognize that soil inorganic mineral surfaces can act as catalysts to increase the reaction rates of chemical oxidation, chemical reduction and chemical hydrolysis. For example, soil inorganic mineral surfaces possess iron oxides, aluminum oxides and adsorbed oxygen which can catalytically react with organic chemicals present in soil. This seminar will address the nature and extent of at least one major type of surface-catalyzed reaction.

BULK HYDROCARBON MOVEMENT THROUGH SOIL PORES

A considerable amount of concern has arisen over the past

few years regarding the presence of bulk hydrocarbons in soilgroundwater systems. The physical reaction of some bulk hydrocarbons with soil will cause a significant increase in soil permeability relative to water. This seminar will address the nature and extent of soil permeability changes caused by at least one type of bulk hydrocarbon, if time permits.

Rational Approaches to Selecting, Performing and Interpreting Medical Tests In a Medical Surveillance Program

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INTRODUCTION

The hazardous waste work environment presents several problems that are unique in terms of selecting and carrying out medical surveillance of workers. Large quantities of a great variety of hazardous materials are, by definition, present at the work site. Combustion or reaction products may be present as well as unknown contaminants which were contained in the original material.

The work force is, in general, well trained and well protected in terms of personal protective equipment, and actual exposures on a day-to-day basis are probably very small unless some type of emergency or improper procedure occurs. However, workers frequently move from site to site and may be potentially exposed to hundreds of toxic materials in the course of a work year. Since medical examinations and tests are selected in part to examine the effects on the target organs of the toxic agents to which the person is exposed, this wide variety of toxic materials exposures makes test selection a problem.

MEDICAL SURVEILLANCE OBJECTIVES

A number of major objectives are pursued in carrying out medical surveillance. The first is to establish a baseline for an individual to determine whether there is a body burden of toxic agents and, also, whether the body itself is healthy. While norms have been established for many tests, there are large individual differences within the range of normals and for each individual. Establishing a baseline is an important way of detecting early trends in disease, in determining whether illnesses may be work related, in detecting pre-existing disease before an individual has any exposure and in determining fitness for employment (for example, the ability to carry out heavy labor in a highly stressful environment, tolerating heat in an enclosed suit or the ability to wear a respirator). Another important objective is to comply with regulations for hazardous waste workers.

TESTING

Criteria for determining who to test include examining the extent and duration of exposure and the protective equipment required. Other factors to be considered include personal factors such as age and sex, since endocrine and other functions may be affected under certain conditions of exposures.

The selection of a test protocol will be considered and examples presented. They are selected in order to establish individual baselines, determine the fitness of the worker and then determine whether or not there has been undue absorption of toxic agents. This increase in body burden may exist in the form in which a material entered the body or as a breakdown product. The other major test procedures are those which measure organ function to determine whether those organs have suffered as a consequence of absorption.

Determining the test frequency requires examining the intensity of exposure, the number and types of materials to which workers may have been exposed, the exposure intervals and unusual situations or emergencies where there may have been heavy exposure or a loss of protection.

A major problem is quality control since individuals may be working in different parts of the country and may be examined by a variety of medical facilities or individuals with differences in techniques, norms and skills. Thus, standardization, accuracy, reliability, handling and storage of data are critical and will be discussed with examples.

CONCLUSIONS

Finally, how these data are interpreted and utilized to safeguard health will be summarized. These would include a discussion of their use in an emergency, use for plotting of trends to allow early detection of disease at a reversible stage and use of other methods to prevent disease and maintain the health of the work force. The unique aspects required for medical surveillance of the hazardous waste worker will be the central theme of the seminar.

SEMINAR OUTLINE

- 1. Purpose of medical surveillance
 - Establish a baseline
 - Detect pre-existing disease
 - Determine fitness for employment
 - Comply with regulations
 - Detect work-related illness
 - Detect early trends
- 2. Criteria for determining who to test
 - Extent and duration of exposure
 - Protective equipment requirements
- 3. Selecting a test protocol
 - Tests to establish individual baseline
 - Tests to determine fitness of worker
 - Tests to quantitate toxic materials or their metabolites in the body
 - Tests to measure organ function

4. Determining test frequency

- Intensity of exposure
- Nature of exposure (number and type of materials)
- Exposure intervals
- Unusual situations and emergencies

- 5. Quality control issues in a medical surveillance program
 - Standardizing data collection
 - Accurate, reliable data
 - Storage and retrieval of data
- 6. Interpreting and using medical surveillance data to safeguard health
 - In an emergency, provides baseline information on individual norms or pre-exposure levels, special susceptibility and pre-existing disease
 - Routine monitoring over time can show trend toward

abnormality, allowing early detection of disease at a reversible stage and trigger a review of work-place procedures for preventing exposure and testing of others similarly exposed

- Examinations provide an opportunity to review and reinforce good health and work practices, answer questions and allay fears
- Signs of frank disease, either work or non-work related, can be detected and treated
- Grouped data can be used to detect trends which may not have been evident in the individual

Superfund Risk Assessment: The Process and Its Application to Uncontrolled Hazardous Waste Sites

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INTRODUCTION

As part of the Superfund program to mitigate problems caused by uncontrolled hazardous waste sites, the U.S. EPA has adapted general risk assessment procedures to analyze threats to public health at those sites. This paper describes the basic components of the Superfund risk assessment process that address public health concerns. Illustrations of how risk assessment may be used in the field are included.

CERCLA authorizes the federal government to respond directly to releases, or threatened releases, of hazardous substances that may endanger public health, welfare or the environment. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) establishes a framework for implementing CERCLA by outlining the process for developing and evaluating various remedial alternatives for Superfund sites. The NCP describes two major elements of the site remedial planning process; the remedial investigation (RI) and the feasibility study (FS). During the RI, field investigators obtain site characterization data necessary to determine what responses, if any, should be considered and evaluated for a site. During the FS, remedial alternatives are developed to effectively address site contamination problems identified in the remedial investigation.

The Superfund Record of Decision (ROD) summarizes the information from the remedial investigation and the FS. The ROD describes the remedial action chosen for a site and how it meets the requirements for consideration of public health, cost-effectiveness and compliance with RCRA and other environmental statutes. The RODs include specific cleanup levels for contaminated soils and water based on health-based criteria and an evaluation of remedial alternatives for a site.

Chapter Five of the Guidance on Feasibility Studies Under CERCLA (U.S. EPA, 1985) summarizes a method for public health evaluation at Superfund sites and provides the basis for the U.S. EPA's Superfund risk assessment process and procedures manual, the Superfund Public Health Evaluation Manual (SPHEM) (U.S. EPA, Dec. 18, 1985), which describes the process. The risk assessment process is based on several EPA documents that detail major aspects of risk assessment including guidelines for carcinogenic risk assessment, exposure assessment, mutagenicity risk assessment, assessment of suspected developmental toxicants (49 FR 46294-46331) and health risk assessment of chemical mixtures (50 FR 1170-1176), which provides a framework for public health evaluation. The goals of the process are to ensure that Superfund remedies adequately protect public health and that the risk assessment process used is consistent. A similar guidance has been developed by the U.S. EPA's Office of Waste Programs Enforcement (OWPE) for endangerment assessments at enforcement-lead sites. This guidance is described in The Endangerment Assessment Handbook (OWPE, U.S. EPA, Aug. 1985). To supplement these procedures manuals, critical chemical and toxicity data from Health Effects Assessment documents and other U.S. EPA-approved sources for more than 200 chemicals typically found at uncontrolled waste sites have been summarized in the appendices to the SPHEM.

In developing these procedures, the U.S. EPA recognizes that public health evaluations cannot be reduced to simple, cookbook procedures. State-of-the-art risk assessment techniques require the use of informed scientific judgment. Each site poses a unique set of circumstances that must be addressed on a caseby-case basis.

THE SUPERFUND PUBLIC HEALTH EVALUATION PROCESS

As described in the SPHEM, Superfund public health evaluations are conducted in two phases. The baseline evaluation, which is a major part of the evaluation, examines the effects of taking no action at the Superfund site and is initiated early in the remedial process. The second phase involves refining initial design ideas for remedial alternatives to address specific health concerns at the site and evaluating the consequences of implementing those alternatives. Environmental concerns also may be important and may actually drive the cleanup at some sites.* Those considerations are made separately from the public health risk assessment, however.

Baseline Public Health Evaluation: Assessing Initial Site Conditions

The risk assessment process is a generic framework that is broadly applicable to many sites. The level of effort required for a site is a site-specific decision determined in part by the complexity of the site, number of chemicals present, availability of toxicity data and necessity for precision of the results. As a consequence of attempting to cover a wide variety of sites, many of the process components, steps and techniques described in the manual

*At the Burnt Fly Bog site, NJ (ROD signed Nov. 16, 1983), NTIS No. PB85 213676/AS), excavation of lagoons and wetlands was undertaken to remove threats to public health and the environment. However, wetlands will be restored to natural contours and revegetated based on the environmental considerations of erosion control and biological restoration.

will not apply at every site.

The baseline evaluation consists of five steps:

- Selection of indicator chemicals
- Determination of human exposures
- Estimation of human intakes
- Evaluation of toxicity
- Characterization of risk

Selecting Indicator Chemicals

The Superfund public health evaluation is based on selected chemicals, referred to as "indicator chemicals," that pose the greatest potential health hazard at a site. It may be both impractical and unnecessarily time consuming to assess the risk of every chemical.

Indicator chemicals are chosen to include the most toxic, mobile and persistent chemicals, as well as those present in the largest amounts. For each chemical, toxicity is examined in light of concentrations measured in specific environmental media. In addition, various chemical and physical properties that affect the potential for a substance to migrate or persist in the environment are considered.

Determining Extent and Duration of Human Exposures

Once indicator chemicals have been selected, the extent and duration of human exposure to each contaminant can be estimated. Chronic and subchronic exposures are evaluated for each human exposure pathway identified at the site using monitoring data and environmental fate modeling. Details of exposure evaluation are given in the *Superfund Exposure Assessment Manual* (U.S. EPA, 1986). The results of this step are estimates of longterm and short-term concentrations of indicator chemicals at all exposure points.

Comparing Projected Concentrations to Standards

At this point in the process, the projected concentrations of indicator chemicals at exposure points are compared to "applicable or relevant and appropriate" environmental requirements established in other environmental programs, subject to a few exceptions (50 FR 47,975 to be codified at 40 CFR §300.68(i)(1)). Examples of requirements that the Agency has determined may be applicable or relevant and appropriate for the purpose of risk assessment depending on site conditions are Safe Drinking Water Act Maximum Contaminant Levels (MCLs) and Clean Air Act National Ambient Air Quality Standards (NAAQS).

In the ROD, a variety of other requirements may serve as the basis for choosing a final remedial alternative. For example, PCB waste oils at the Laskin/Poplar Oil site in Jefferson, Ohio (ROD, 8-9-84) were removed and incinerated in compliance with 40 CFR 761 requirements for PCBs under TSCA. At Triangle Chemical, Texas (EPA/ROD RO6-85-007), RCRA guidelines for tank closure, floodplain management under Executive Order 11988 and Clean Water Act MCLs were included in the analysis of remedies.

For some Superfund sites, no applicable or relevant and appropriate requirements may exist for all the selected chemicals. In these situations, a quantitative risk assessment must be completed. The final public health evaluation may include both a standards comparison and a quantitative risk characterization.

Estimating Human Intake

After estimating exposure point concentrations, the assessment team must estimate the amount (in mg/kg/day) of a substance a person takes in by breathing contaminated air, drinking contaminated water and ingesting contaminated soil. Standard assumptions about consumption of air, water and soil are combined with estimated concentrations in various media to generate intake values unless human activity patterns that affect intake are available. Other human exposure pathways may be developed in consultation with U.S. EPA headquarters, if necessary for a specific site.

Evaluating Toxicity and Characterizing Risk

The next step in the process is to evaluate the toxicity associated with each chemical. For noncarcinogens, toxicity values are presented in terms of acceptable intake levels for chronic and subchronic exposures. For risk characterization, these acceptable levels are compared to estimated intake levels for potentially exposed individuals. Multiple chemical exposures also are assessed using an approach based on EPA's proposed "Guidelines for Health Risk Assessment of Chemical Mixtures" (50 FR 1170-1176). This approach encourages the assessment team to consider the cumulative "insult" from a number of chemicals that induce the same health effect.

For carcinogens, upper bound carcinogenic potency factors are combined with estimated intake levels to calculate upper bound confidence limits on carcinogenic risks. The U.S. EPA's proposed guidelines for mixtures permit the use of "risk additivity" for carcinogens. This procedure allows estimation of a total upper bound carcinogenic risk by summing the risks posed by individual indicator chemicals.

Refining Designs and Evaluating Remedial Alternatives

Ultimately, remedial alternatives under consideration will be analyzed with respect to public health and environmental protection, consistency with applicable or relevant and appropriate requirements, technical feasibility and cost; and one alternative will be selected and presented in the ROD. The NCP requires the chosen remedy to "mitigate and minimize threats to and provide adequate protection to public health and welfare and the environment" [50 FR 47,975, to be codified at 40 CFR §300.68 (i)(1)].

Consideration of cost is one of the important inputs to the risk management decision. For example, at the Jibboom Junkyard site, California (EPA/ROD RO9-85-008) as amended on Oct. 4, 1985, excavation and off-site disposal at an RCRA approved hazardous waste disposal facility was chosen as the selected alternative because it reduced soil lead concentrations to below 500 ppm. Removal was chosen over capping, a lower cost alternative, because of threat of possible groundwater contamination should groundwater levels in the area rise.

However, providing an alternate water source to replace contaminated wells was chosen as the remedial action at the Matthews Electroplating site in Roanoke, Virginia (ROD, 6-2-83). This option represented the cost-effective remedy that was protective of public health and the environment. Additional action at the site (i.e., capping) was determined to be unnecessary because it provided no additional public health or environmental protection for the additional expenditure.

At the McKin site, Maine (EPA/ROD RO1-85-009) contaminated soil will be cleaned up to levels that are protective of the groundwater and other potential routes of exposure. Groundwater monitoring will be conducted to ensure no migration of contaminants during the remedial activity.

Applicable or relevant and appropriate requirements serve as the basis for remedies at a site if they are available for chemicals of interest. If not, a risk-based approach is used. Remedial alternatives are refined as necessary to ensure that options considered in the ROD span a carcinogenic risk range of 10^{-4} to 10^{-7} . Regardless of what risk level is chosen, health risk from potential carcinogens generally drives the development of performance goals for remedial alternatives.

The 10^{-6} carcinogenic risk often is chosen as the target risk out of the carcinogenic risk range of 10^{-4} to 10^{-7} . At the Reilly Tar site, St. Louis Park, Minnesota (ROD, 6-6-84), the ROD specifies that the 10^{-6} cancer risk level for polyaromatic hydrocarbons, the chemicals of chief concern at the site, was chosen as the goal for cleanup of a contaminated aquifer.

In other situations, other values in the risk range ultimately may be chosen for the remedial action. For example, at the McKin site in Gray, Maine (EPA/ROD/RO1-85-009), a 10^{-5} lifetime statistical cancer risk level was chosen for trichloroethylene, the chemical of highest concern, because of relatively low levels of uncertainty regarding levels of contamination in the affected aquifer following 5 yr of monitoring, no known regular human use of the contaminated aquifer, consideration of natural attenuation mechanisms and consideration of the effect of remedial action at the site.

The 10^{-5} cancer risk level also was chosen for groundwater at the Old Mill, Ohio site (EPA/ROD RO5-85-018) because that level can be reached with 30 yr of treatment whereas the 10^{-6} cancer risk level would not be reached for 100 yr. Background may be chosen as the cleanup level as was the case at Triangle Chemical, Texas (EPA/ROD RO6-85-007).

In addition to addressing the long-term health effects at a site,

short-term effects of implementation also must be considered for all remedial alternatives. For example, it may be important to consider inhalation risks to nearby residents if installation of a particular technology involves substantial excavation and dust generation. This evaluation may be qualitative or quantitative and is used to develop management practices to control releases during construction.

CONCLUSIONS

Overall, the public health evaluation of remedial alternatives is an iterative process that involves refining the design of specific remedies. A risk-based approach for controlling releases usually will demonstrate that one or two chemicals in the mixture are responsible for most of the risk. These chemicals actually drive the risk assessment and, therefore, drive the performance goals for remedial alternatives. Once these chemicals are sufficiently controlled, the risks from other chemicals in the mixture are likely to be negligible in comparison.

When completed, the public health evaluation is submitted as a chapter in the feasibility study report, available for review by the public. Feasibility studies are required for both fund-financed and enforcement-directed cleanups. Consequently, some form of public health evaluation will be required at both types of sites.

Proper Design and Installation Techniques for Groundwater Monitoring Wells

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INTRODUCTION

The installation of groundwater monitoring wells for the purpose of detecting trace levels of both organic and inorganic contaminants in groundwater systems is a common practice in many waste disposal and chemical spill scenarios. It is estimated that tens of thousands of monitoring wells have been installed over the past 5 yr, and that thousands more are installed annually. Many of these wells are put in by consultants and contractors who are not aware of the proper practices for monitoring well construction. As a result, many existing and currently installed monitoring wells have critical design flaws or were and are installed utilizing methods and/or materials that adversely affect the quality of groundwater samples taken from them. Because the objective of most groundwater monitoring programs is to obtain "representative" groundwater samples, or samples that retain both the physical and chemical properties of the groundwater being monitored, proper groundwater monitoring well design and installation techniques to minimize the potential for sample chemical alteration are imperative.

WELL PROBLEMS

Most groundwater monitoring well design and installation problems can be traced to the mistaken belief that a "cookbook" approach, which ignores site-specific hydrogeologic, geographical and contaminant-related conditions, can be used in all situations. The fact is that each monitoring well site is unique, thus requiring a unique design for each monitoring well. The designer must develop well design and installation specifications that take into account anticipated site-specific conditions and are flexible enough to accommodate alterations necessitated by unanticipated conditions encountered during drilling.

Other groundwater monitoring well design and installation problems stem from the fact that there are few professionals who are adequately trained and experienced in proper monitoring well construction practices and procedures. It must also be realized that the analytical power of modern laboratories is now reaching the parts-per-trillion detection level; the means of gaining access to the subsurface to obtain groundwater samples for analysis is crude by comparison. Still, most potential sources of sample chemical alteration inherent in the monitoring well construction process can be anticipated and controlled. Consultants and contractors need a workable set of flexible guidelines for monitoring well design and installation which is adaptable to a wide variety of groundwater monitoring situations.

GUIDELINE DEVELOPMENT

The first step toward developing guidelines for monitoring well design and installation is identifying the areas in which most problems arise. Among the most common monitoring well design flaws and installation problems are the following:

- Use of inappropriate well casings or well screen materials (i.e., materials that have not been selected to be compatible with the hydrogeologic environment, anticipated contaminants or the requirements of the groundwater sampling program), resulting in sample chemical alteration or failure of the well
- Use of non-standard well screen (i.e., field-slotted or drilled casing), or use of incorrect screen slot sizing practices, resulting in sedimentation of the well and the acquisition of turbid samples throughout the life of the monitoring well program
- Improper length and placement of the well screen, making the acquisition of water level or water quality data from discrete zones impossible
- Improper selection and placement of filter pack materials, resulting in sedimentation of the well, plugging of the well screen, groundwater sample chemical alteration and potential failure of the well
- Improper selection and placement of annular seal materials, resulting in alteration of sample chemical quality, plugging of the filter pack and/or well screen or cross-contamination from improperly sealed-off geologic units
- Inadequate surface protective measures, resulting in surface water entering the well bore, alteration of sample chemical quality or damage to/destruction of the well
- Improper or inadequate well development, resulting in acquisition of sediment-laden samples, grout contamination of the filter pack and subsequent alteration of sample chemical quality and reduced well yield.

Any one or a combination of these design/installation problems could result in a determination that a well or a series of wells is unsuitable for obtaining representative groundwater samples. In many cases one or more of these errors necessitates the abandonment of the improperly designed/installed well and the installation of replacement wells, which can be very costly and time-consuming. The use of proper groundwater monitoring well design and installation practices is thus essential to ensure timeand cost-efficient acquisition of representative groundwater samples.

PROPER WELL DESIGN

Proper design and installation of groundwater monitoring wells requires a thorough review of a variety of site-specific conditions as well as an up-to-date knowledge of well design and installation practices and procedures. Site-specific design considerations include:

The purpose or objective of the groundwater monitoring pro-
gram (i.e., water quality monitoring vs. water level monitoring)

- Surficial conditions, including topography, drainage, climate, seasonal variations in climate and site access
- Known or anticipated hydrogeologic settings, including type of geology (unconsolidated/consolidated), aquifer physical characteristics (type of porosity, hydraulic conductivity), type of aquifer (confined/unconfined), recharge/discharge conditions and aquifer interrelationships
- Characteristics of known or anticipated contaminants (chemistry, density, viscosity, reactivity, concentration)
- Anthropogenic influences (i.e., man-induced changes in hydraulic conditions)
- Any regulatory requirements that must be met

A unique set of site-specific design considerations exists for each site and, in fact, for each well installation. This requires that each well be designed as a unique structure.

To develop a knowledge of proper monitoring well design practices, it is first necessary to understand the individual design components of monitoring wells and how they combine to produce the final structure—the well itself. While it is not practical to describe a "typical" monitoring well in which the design components are fixed, it is possible to describe the individual design components, which include the following:

- Well casings
- Well intakes (screens)
- Filter packs
- Annular seals
- Surface protective measures

These individual design components can be tailored and assembled to suit the site-specific considerations described above.

PROPER WELL INSTALLATION

Proper installation of groundwater monitoring wells requires a knowledge of state-of-the-art practices for well installation both to avoid potential contamination of the well bore or well caused by the well construction process itself and to permit easy access to the subsurface for groundwater sampling and water level measurement. Proper joining and placement techniques for well casing and screen, slot-sizing procedures for screens, placement and sizing techniques for filter packs, placement procedures for annular seals, installation of surface protective measures and well development techniques all must be used to ensure that a monitoring well will perform as intended.

APPENDIX SEMINAR OUTLINE

- I. Factors Influencing Groundwater Monitoring Well Design and Installation
 - A. Objectives of the Monitoring Program
 - **B.** Surficial Characteristics
 - C. Hydrogeologic Settings
 - D. Facility and Waste Characteristics
 - E. Anthropogenic Influences
 - F. Regulatory Requirements

- II. Groundwater Monitoring Well Pre-Design/Installation Considerations
 - A. Desired Method of Drilling
 - B. Anticipated Groundwater Sampling Method/Equipment
 - C. Well and Aquifer Testing Requirements
 - D. Potential Use of Well Logging (Borehole Geophysical) Tools
 - E. Method of Well Development Required
 - F. Method of Water Level Measurement Anticipated
- III. Design Components of Groundwater Monitoring Wells
 - A. Well Casings
 - 1. Purpose of the Casing
 - 2. Effects of Casing Materials on Groundwater Sample Integrity
 - 3. Selection of Casing Sizes
 - 4. Coupling Procedures for Joining Casing
 - B. Well Intakes (Screens)
 - 1. Purpose of the Well Intake
 - 2. Types of Well Intakes; Advantages/Disadvantages of Each
 - 3. Selection of Intake Slot Sizes
 - 4. Discussion of Effect of Well Intake Length on Groundwater Measurements
 - C. Filter Packs
 - 1. Purpose of the Filter Pack
 - 2. Types of Filter Packs; Where Each Type is Appropriate
 - 3. Selection of Filter Pack Materials
 - D. Annular Seals
 - 1. Purpose of the Annular Seal
 - 2. Materials Used for Annular Seals
 - 3. Methods of Emplacement of Annular Seals
 - 4. Methods for Evaluating Annular Seal Integrity
 - E. Surface Protective Measures
 - 1. Protection from Surface Water Runoff
 - 2. Protection from Physical Damage and Vandalism
- IV. Types of Monitoring Well Completions
 - A. Single Well Completions
 - 1. Single Short Screened Interval
 - 2. Single Long Screened Interval
 - 3. Multiple Screened Intervals
 - B. Multiple Well Completions in a Single Borehole
- V. Monitoring Well Development
 - A. Purpose of Well Development
 - B. Discussion of Methods Available; Advantages/Disadvantages of Each
 - C. Impact of Non-Development on Sample Integrity
- VI. Groundwater Monitoring Well Post-Design/Installation Considerations
 - A. Surveying Well Casings to a Common Datum
 - B. Identification of Wells
 - C. Mapping of Well Locations
 - D. Reporting Details of Monitoring Well Installation
 - E. Well Maintenance

Interrelationship Between Superfund and RCRA

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SUMMARY

For the past several years RCRA requirements have played an important role in the analysis and selection of Superfund remedies. Implementing RCRA consistent remedies is called for by the policy on "CERCLA compliance with other Environmental Statues" (published in the November 20, 1986, revision to the National Contingency Plan). The CERCLA compliance policy was largely embodied in the passage of the Superfund Amendments and Reauthorization Act of 1986 (SARA). RCRA is the most important environmental statute to analyze because it is the most complex and because RCRA comprehensively manages hazardous waste. The goals of this seminar will be to present an analytical framework for evaluating and incorporating RCRA requirements into Superfund remedies.

Compliance with the other environmental statutes serves two primary purposes. First, the requirements help in the selection of remedies by either specifying a safe level in the environment or directing the way in which hazardous waste should be treated or managed. Secondly, following them helps to assure a reasonable level of consistency between various Superfund sites.

The compliance provisions of SARA, Section 121 (d)(1), distinguishes between "applicable" and "relevant and appropriate" requirements. "Applicable" requirements are those standards that otherwise legally would be required. Requirements are "relevant" if they would be applicable for jurisdictional restrictions. Relevant requirements that are not appropriate to the Superfund site may be modified or not used at all. Superfund remedies must be consistent with relevant and appropriate requirements unless a statutory waiver is used.

State's requirements are included under the new statute where applicable or relevant and appropriate. (In the past, State standards were considered and used unless a specific justification was prepared in decision documents.)

RCRA requirements vary substantially depending upon the scope and character of the CERCLA actions. There are at least 8 types of RCRA requirements that are important when developing and evaluating CERCLA response actions. Knowing when these requirements are applicable or relevant and appropriate and how they actually affect remedy configuration is very important in meeting the statutory mandates.

RCRA Regulations Potential Use

Clean Closure

Determining extent of removal

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Because of the greater problems at CERCLA sites, RCRA requirements must be applied flexably to allow feasible actions appropriate to the site circumstances. At many Superfund sites there are no distinct areas of contamination and solutions to problems that often apply across a site.

Which RCRA requirements may be applicable or relevant and appropriate is site specific and action specific. For example, a containment remedy where the waste is not treated will only need to meet land disposal requirements. However, if the same waste is treated and disposed in a new location on-site, the following requirements may apply:

- Treatment
- Land Ban
- Design and Operating Standards
- Location Standards
- Land Disposal Closure

Therefore, it is important to analyze potential RCRA requirements early in the R1/FS process so that remedies can be evaluated that meet or exceed minimum requirements.

Risk/Decision Analysis Module (RIDAM) In Expert Systems

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ABSTRACT

An expert system, Hazardous Wastes and Management Expert System (HAWAMAX), has been conceived and is being developed at Hazardous Materials Control Research Institute. HAWAMAX is designed to provide the "best" advice in a timely fashion to site planners, managers or other decision-makers on how to improve the site and its affected environment until it becomes "safe."

The HAWAMAX expert system is combined with the Risk/Decision Analysis Module (RIDAM) that incorporates all the field and laboratory data and the socio-economic considerations. RIDAM performs both risk assessment and decision analysis based on the scientific inferences and decision-makers' judgemental inputs.

RIDAM, Risk/Decision Analyzing Module, is capable of identifying, classifying, simulating, estimating and comparing the risks of all potential actions and assessing the acceptability of the overall costs imposed on both voluntary workers and involuntary public. RIDAM can also generate multiple management/control approaches in order to eliminate or minimize some of the risks and conduct a systematic analysis of all potential consequences resulting from each of the managerial or control courses of action. In addition, a comprehensive assessment and ranking of choiced courses of activities will be developed for ultimate judgement by the decision-makers together with sensitivity analysis.

HAWAMAX

The HAWAMAX expert system is a computer analysis package with the capability of performing at the level of human experts in specific fields. It is possible to build expert systems that perform at remarkable levels. Though several methods exist for designing expert systems, rule-based systems have emerged as the popular architecture. Deriving or extracting knowledge from relatively easily understand facts and rules, rule-based systems offer surprising power and versatility. HAWAMAX is a rule-based expert system that operates RIDAM the way a human expert would to determine three different sets of decisions: (1) risk estimation and assessment, (2) risk managerial actions and (3) consequences evaluation. The preferential ranking activities will be developed together with the description of consequences for the final most "satisfied" choice by decision-makers.

As shown in Figure 1, RIDAM is the "Centerpiece" module inside the HAWAMAX system which consists of four other modules:

- Knowledge-base of Rules and Facts Module
- Inference Module
- Environmental and Site Description Module
- Data Base Module



Figure 1 The Hazardous Wastes Management Expert (HAWAMAX) Components

The Knowledge-base of Rules and Facts Module contains sets of planning, designing, engineering, monitoring and regulating rules, standards, considerations, functions and specifications in descriptive formats. The Inference Module extracts the pertinent rules and facts and determines alternative feasible plans and designs subject to the identified specifications. It also organizes the output data into files according to hypothesized environmental and site characteristics. These are then fed into the Data Base Module to create and enhance the bases of inference. The Inference Module is designed to generate a series of output files in stochastic nature through an array of simulation models developed by human experts.

The Environmental and Site Description Module compiles all functional and coherent data and descriptive relations defining site and environmental consideration to assist the decision-makers' understanding of the physical, chemical, geological and biological interactions among sites, pollutants, potential hazards, pathways, short-term and long-term effects, socioeconomic impacts and special legal and regulatory requirements.

SOFTWARE

The software requirements of HAWAMAX are primarily for the inference Module (IM) and Risk/Decision Analysis Module (RIDAM). The Inference Module (IM) is written in LISP, while RIDAM is being developed in Fortran. Both will be developed on a PC under respectively common LISP and Fortran 80.

RIDAM

RIDAM is the final driver segment of the HAWAMAX system and will begin with the risk definition through the final evaluation of alternative managerial approaches. As shown in Figure 2, the following subcomponents are included:

- Risk Identification Processor
- Risk Information Processor
- Alternative Managerial Course of Actions Generator
- Risk Prevention and Containment Controller
- Risk Acceptability Evaluator
- Costs and Benefits Estimation
- Decisions Attributes Processor
- Stochastic Events Assessor
- Intangible Factors Evaluator
- Utility Function Module
- Decision Analysis Processor
- Sensitivity Analysis Generator
- Output and Display Processor

In this seminar, the logical and analytical backgrounds of

RIDAM will be presented in detail. Special examples illustrating the applications of RIDAM and its interactions with other components as shown in Figure 2 will be discussed.

Multiattribute Decision Analysis

This evaluation process is accomplished by the following analytical procedures:

- Systematically organize the hazardous waste management problems into a sequential decision-making problem
- Develop an appropriate multiattribute utility function for the consequence evaluation while incorporating risk as one attribute
- Identify and estimate all probability values for all chance events
- Estimate the relative weight values for each of the attributes
- Compute the expected utility values based on utility functions and probability values for all other events
- · Compute the courses of actions based on expected utility values

Illustrative examples will be presented to demonstrate the flexibility and versatility of RIDAM.



Figure 2 Risk/Decision Analysis Module (RIDAM)

Geophysical Techniques for Sensing Buried Wastes And Waste Migration: An Update

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INTRODUCTION

Traditional approaches to subsurface field investigations at hazardous waste sites often have been inadequate because many investigations have commonly relied upon point measurements. When a monitoring well is installed to characterize the level of contaminants, there is usually utmost confidence in the results of the analysis to the mg/l concentration level or less. Yet, the source of the sample with regard to the representativeness of the monitor well's location and the screen depth and interval is almost totally ignored. As a result, samples will not necessarily be representative of site conditions.

It is difficult and probably impossible to characterize the natural conditions with 100% accuracy. However, we need to achieve a reasonable level of accuracy in subsurface evaluation or all the modeling, engineering and decision-making will often be unacceptably inaccurate. The need for complementary approaches to subsurface investigation has emerged because of these problems.

Over the past few years, numerous new, modified and combinations of subsurface investigation techniques have evolved. The application of geophysical techniques is one of those emerging approaches which provides a level of insight necessary to improve upon the accuracy of subsurface investigation.

A report entitled Geophysical Techniques for Sensing Buried Wastes and Waste Migration was written in 1983 to meet the U.S. EPA's initial needs in the area of geophysics. This technology transfer document has been published and distributed by NWWA and NTIS. This paper is a review and update which expands upon this publication.

Airborne, surface and downhole geophysics may be applied to evaluate hydrogeologic conditions and in some cases even map contaminants. The selection of the method or methods depends on the size of the site and the type and amount of data required. There are many geophysical methods that may be used: (1) those which provide geologic and structural data, such as the seismic and gravity methods, and (2) those which also can detect and map contaminants, such as the electrical methods. Since electrical resistivities of geologic formations are highly dependent upon the amount of dissolved solids in the groundwater, both resistivity and electromagnetic geophysical methods are ideally suited to map inorganic contaminants which have high specific conductance.

This work focuses on the surface and downhole geophysical methods. A number of surface geophysical methods can be employed, including:

- Ground Penetrating Radar
- Electromagnetics
- Resistivity

- Magnetics
- Seismic Refraction
- Seismic Reflection
- Microgravity
- Metal Detection

As depth increases, the accuracy and the detail obtained by surface geophysics decreases. In contrast, the downhole geophysical logging methods not only provide considerable detail, but also maintain the detail independent of depth. If existing wells are available, measurements of lithology or hydrogeologic characteristics such as density and porosity as well as some contaminant measurements can be obtained at little cost. The downhole methods to be considered include:

- Single Point Resistance
- Natural Gamma
- Induction (electrical conductivity/resistivity)
- Neutron-Neutron (moisture/porosity)
- Television
- Spontaneous Potential (SP)
- Caliper
- Resistivity
- Gamma-Gamma (density)

Both the surface and downhole geophysical methods measure bulk physical and electrical properties of the soil and rock and allow a high density of measurements to be taken for a relatively small cost. By increasing the spatial density of sampling, a better characterization of site conditions can be made prior to drilling and sampling, therefore optimizing the quantitative analysis obtained. Knowing how to select an optimum field approach is of critical importance to a successful field investigation. The objectives of this paper are to introduce some of the commonly used geophysical methods and their applications and provide aids to help select the right methodology to ensure reasonably correct decisions to improve the accuracy of subsurface information.

APPLICATION OF GEOPHYSICAL METHODS

There are three major areas for the application of geophysical methods at hazardous waste sites: (1) assessing natural conditions, (2) assessing contaminant migration and cultural factors which may impact them and (3) delineating buried wastes.

Assessing Natural Conditions

One of the most important tasks of any site investigation involves evaluating the site's natural setting. In many cases, mapping natural geologic conditions with geophysical techniques provides an insight not obtained with a limited boring program. Characterization of the lateral and vertical extent as well as any discontinuities of sand and clay lenses, fracture zones, buried relic stream channels and so forth will significantly improve the accuracy of hazardous waste site assessment. In addition to characterizing the site geology, an evaluation of hydrologic properties sometimes can be made.

Assessing Contaminant Migration

The mapping of contaminant plumes often can be easily accomplished using electrical methods. Because inorganics are often more electrically conductive than groundwater, their extent can be mapped both laterally and vertically using electrical techniques. This mapping provides a means of directly characterizing the extent of the contaminant in situ and provides an indication of any anomalies. This assessment can be a vital part in modeling groundwater flow. Furthermore, these methods can be used for time series measurements of plume dynamics. Although organics are usually non-conductive, they are commonly associated with inorganics. If a mixture of organics and inorganics exists, the organics then can be mapped using electrical methods.

In cases where pure organics such as TCE, CTET, gasoline and diesel fuel, etc., exist, geophysics often can be used to define the permeable pathways or top of rock along which the contaminants may migrate. By mapping contaminant plumes in this manner, locations for representative monitor wells can accurately be made, and cleanup costs can be minimized. Cultural features such as buried utilities and tanks which impact flow also can be identified and assessed.

Assessing Buried Wastes

Geophysics can be used to locate and map the extent of buried waste including:

- · Location and boundaries of landfills
- · Location of burial trenches
- Location of buried 55-gal drums
- Location of buried tanks and pipes
- · Location of buried utility lines

SELECTING AN OPTIMUM METHODOLOGY

In developing general guidelines for selecting methodologies, it must be stressed that no single approach or technique (geophysical or otherwise) is a panacea for any site investigation. This paper outlines the advantages and disadvantages of a number of the geophysical methods and provides rules of thumb for their application. A number of examples are given along with approximate costs. The key starting point of any site investigation is a clearly identified purpose and scope of work; only then can the technical and cost trade-offs be accurately made.

The Role of the Agency for Toxic Substances And Disease Registry in Superfund Response

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ABSTRACT

Improper disposal of chemicals in the United States has produced a large number of uncontrolled hazardous waste sites. Potentially harmful materials from these sites have contaminated groundwater, surface water, soils and air. In response to the threat these sites pose to health and to the environment, Congress enacted CERCLA in 1980. The Agency for Toxic Substances and Disease Registry (ATSDR) was one result of this law. Congress charged ATSDR with specific tasks designed to improve the understanding of the relationships between toxic waste exposure and illness. ATSDR's response to the Congressional charge is described in this manuscript.

ATSDR works closely with local, state and Federal agencies to eliminate or reduce illness, disability and death resulting from human exposure to toxic substances at spills and waste disposal sites. ATSDR's administrative office supervises two program offices: the Office of External Affairs (OEA) and the Office of Health Assessment (OHA). OEA is responsible for activities outside of the Agency, such as managing interagency agreements and coordinating the creation of disease/exposure registries.

OHA is responsible for conducting most of the CERCLAmandated tasks. It has a technical support staff whose primary areas of expertise are health assessment reviews and exposure studies.

ATSDR is active in many health-related areas of America's hazardous waste problem. Today, ATSDR's primary emphasis is on environmental public health assessment which involves a multidisciplinary, preliminary review of all available data on a particular hazardous waste site. The purpose of this review is to assess the nature and magnitude of any threat to human health. In such health assessments, environmental pathways and exposure pathways are carefully studied and the estimated potential risk to human health is determined. These assessments help health personnel decide whether full-scale health or epidemiological studies are warranted and whether medical evaluations of exposed populations should be undertaken. The U.S. EPA considers health assessments in evaluating the need for remedial activities.

ATSDR's responsibilities, how the Agency is organized and the role it plays in Superfund response are described in this manuscript. The health assessment review process is discussed in detail and the complexities surrounding the evaluation of environmental and exposure pathways are examined. Uncontrolled hazardous waste sites are a major public health problem in the United States; they also are politically significant. Learning more about ATSDR and the health assessment process should prove valuable to any-

•This paper is a summary of a seminar manuscript by the same title. The areas discussed in this summary are covered in significantly greater detail by the full manuscript. one concerned with hazardous waste.

INTRODUCTION

In 1980, Congress passed CERCLA which contains a provision to establish the Agency for Toxic Substances and Disease Registry (ATSDR). This new agency was created within the Public Health Service to carry out the health-related responsibilities of CERCLA. Congress charged ATSDR with specific tasks designed to increase what is known about the relationships between toxic waste exposure and illness.

The original concept of ATSDR as defined by these tasks has not changed, but perhaps the Agency's charge has become more specific. ATSDR works closely with local, state and other Federal agencies to reduce or eliminate illness, disability and death resulting from the exposure of the public (and of workers) to toxic substances at spill and waste disposal sites. Beyond the original tasks, ATSDR's mission has expanded to include the performance of health assessments at Superfund sites. Indeed, ATSDR's primary activity is the environmental public health assessment.

ORGANIZATIONAL STRUCTURE

Before proceeding with a discussion of health assessments, some knowledge of the organizational structure of ATSDR is necessary. The Agency is directed by an Administrator who reports to the Assistant Secretary for Health. Day-to-day operational control is provided by the Associate Administrator, who manages the two program offices: (1) External Affairs and (2) Health Assessment.

The Office of External Affairs is responsible for activities outside of the Agency, such as managing interagency agreements and coordinating the development of exposure/disease registries. The Office of Health Assessment contains most of the technical support staff, who are responsible for responding to emergency requests from the field, initiating protocols and training for state capacity building and performing multidisciplinary reviews of uncontrolled hazardous waste sites or any other mandated health-related activity relevant to toxic wastes.

HEALTH ASSESSMENTS

Health assessments are multidisciplinary, preliminary reviews of all available data relevant to the site. The reviews are carried out to evaluate the nature and magnitude of any threat to human health from the site. They involve a thorough assessment of environmental pathways and exposure pathways and ultimately end with some determination of the potential risk to human health posed by the site in question. The purpose of such assessments is to help determine whether full-scale health or epidemiological studies are warranted and whether medical evaluations of exposed populations should be undertaken. Health assessments also assist the U.S. EPA in evaluating planned remedial activities for a site.

Environmental Pathways Assessment

ATSDR assessment of environmental impacts begins with a selection of the contaminants of concern. Concurrent with the selection of indicator chemicals, ATSDR engineers review release mechanisms and the media to which releases might occur. Then the staff starts to evaluate the effects of potential transport or transformation mechanisms. The method ATSDR uses to screen each medium involves both qualitative and quantitative procedures.

Environmental fate mechanisms that potentially may be significant at the site in question are selected by asking simple, generic questions. Quantitative assessment follows. Computer-based models can be used to supplement "best engineering judgment" on decisions concerning in-depth analysis of integrated release sources, environmental transport media and the environmental fate of indicator chemicals.

Provided sufficient data are available, ATSDR's environmental pathways assessment will conclude with considerable information on the chemicals of concern, their fate and the potential routes of human exposure. This information is analyzed by epidemiologists and toxicologists to generate a public health evaluation of the site. These evaluations are known as human exposure assessments.

Assessment of Human Exposure Pathways

Once the site contaminants and environmental pathways data sets are complete, human receptors and exposure pathways can be determined. To present a hazard to humans, the contaminants must get from the environment to those humans. The major routes by which humans can be exposed to environmental contaminants at hazardous waste sites include ingestion, inhalation and dermal absorption. The significance of each pathway depends on site-specific information that is collected and incorporated into a risk assessment.

Estimating the dosage to which humans may be exposed is important in determining the significance of the exposure pathway. Route-specific dosages to a contaminant are calculated and compared with existing standards for human exposure. Often, assumptions must be made when scientific data are unavailable. These assumptions may include considering the "worst case," even if it provides an extremely conservative result that is probably unrealistic.

Characteristics of the site also help determine the significance of the exposure pathways. Physical access to the site and the likelihood of human contact with the contaminated matrix cannot be overlooked when assessing risk. Demographics and cultural characteristics may be important in determining which population segments may be exposed to the contaminants. The exposure potential may be influenced by proximity to the site, daily activities and lifestyle. ATSDR scientists consider all of these factors and more when they characterize the risk to the public health for communities adjacent to hazardous waste sites.

In most cases, the interpretation of site data follows a logical forward sequence in the evaluation of the potential for human exposure and adverse health effects. At times, however, a cluster or increase in adverse health conditions is recognized in a particular area. ATSDR then proceeds to determine if these health effects can be causally linked with exposure to contaminants from a toxic waste site. If the Agency concludes that people potentially may have been exposed, an exposure study may be performed to contribute to the overall utility of any future risk-management decisions.

EXPOSURE STUDIES

ASTDR scientists conduct exposure studies of communities potentially exposed to hazardous waste contaminants. Results of these studies are used to determine if the presence of the contaminant has resulted in either an exposure to the compound (that is, elevated body burden relative to a control population) or an adverse health effect. All available site information and the ATSDR health assessment document are used to identify the potentially exposed population. Questionnaires, developed and administered by the Agency's scientists, are designed to define groups at highest risk of exposure to site contaminants and to determine if there appears to be an associated increased incidence of reported health complaints.

Biologic testing of persons potentially exposed to the contaminants then may be done to determine if they have elevated body burdens and to better understand the relationship between media concentration, bioavailability, uptake, exposure and health effects.

At present, ATSDR is conducting exposure assessments in several communities. Besides addressing a community's health concerns, data generated from these assessments can provide key information that will better define exposure assumptions used for quantitative risk assessments.

EMERGENCY RESPONSE HEALTH ASSESSMENTS

The sudden and uncontrolled release of hazardous materials requires the rapid and systematic use of the health assessment process to prevent local residents from being exposed to hazardous materials or at least to reduce the toxic effects of such exposures. The health assessment process previously described for hazardous waste sites is the same process by which the emergency response is rendered. However, the emergency response requires making and implementing public health decisions with little or no data. Thus, some forethought is necessary if health personnel are to respond adequately.

Protecting public health in an emergency situation is based on two principles. First, the sudden release of hazardous materials represents a new exposure. It is a new health burden that was not present even days earlier. With rapid action, an exposure may be prevented completely, not just limited in duration. Second, only the immediate exposure needs to be addressed immediately. Control decisions should be limited to critical exposure routes. Those decisions not immediately necessary should be deferred to a time when the decision-making process can be more deliberate, less stressed and less prone to error.

On the basis of these principles, the emergency response health assessment identifies likely migration pathways, potential human exposure pathways, populations at risk and actions required to prevent human exposure to sudden toxic releases.

Toward an Effective Strategy For Dealing with Superfund

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INTRODUCTION

The impact of CERCLA and its state counterparts underscores the fact that lawmakers have implicitly promised a substantial amount of risk reduction posed by hazardous substances to society. The promises embodied in these laws, together with the prospects for liability which these laws present, have and will continue to have a profound effect upon the decision-making of domestic corporations, foreign corporations and other parties who may be affected by the laws' liability provisions.

Liability under Superfund may be either direct (as in the case of potentially responsible parties) or indirect (as in the case of insurance companies, investment institutions or successor corporations). The prospects for liability to this second class of parties may appear to be much less obvious because they may never have dealt with the generation or disposal of hazardous substances.

Because Superfund and its state counterparts present such great potential for liability, often of an unquantifiable nature in terms of time and amount, it is becoming imperative that all parties who may be affected by these laws realize that the time has come to devise a long-term strategy for dealing with them. Such a strategy, based upon the author's representation of potentially responsible parties, banking institutions and insurance companies, is summarized below.

STRATEGY ELEMENTS IN COMMON TO ALL PARTIES

Two common elements of any overall strategy, whether it be one employed by a potentially responsible party (PRP) or another party who may become indirectly affected by Superfund type legislation, are discussed first.

First, all potentially affected parties must be knowledgeable about the requirements and provisions of the laws. Although the finer points of the law and case decisions thereunder may be within the province of legal counsel, there is no excuse for parties not taking the time to be thoroughly briefed by counsel or to attend seminars or training sessions where the laws and regulations are discussed. (Herein will be discussed in brief fashion several of the key liability provisions under Superfund as amended in 1986.)

Second, all parties should appreciate that the implementation of Superfund ultimately involves agency decision-making which has at least three key components: the legal component, the scientific or engineering component and the public policy/political component. Parties should hever fail to underestimate the extent of the last component, which may be the most important in finalizing decisions regarding cleanup.

STRATEGY FOR THE POTENTIALLY RESPONSIBLE PARTY

The author's experience at a half dozen Superfund sites in several western states strongly suggests that PRPs will want to seriously consider adopting a strategy that involves the following elements. First, and early in the process (even before a site has been designated for inclusion on the NPL), the farsighted party should form a team including managerial personnel, technical/engineering personnel, legal personnel and, perhaps, public relations personnel. This team should be given the responsibility, as well as the authority, to study a site and, if necessary, implement remedial measures even before a site becomes designated on the NPL.

Second, as soon as notification is received from agency officials concerning PRP status, a party must inform its insurers of the event and attempt to obtain their cooperation in further dealing with events as they unfold.

Third, when and if a property becomes listed on the NPL, a farsighted party should attempt to become involved in the development of information concerning that site and should seriously consider undertaking the RI/FS for that site, even if it requires entering into an enforceable consent agreement with a state or federal agency. The ability to generate information about a site and to use one's experts to argue in favor of conclusions that can be drawn about that information forms one of the few opportunities to "go on the offensive" under Superfund. Unless a party has a truly minimal involvement with a site, an active role in decision-making at the site should be considered.

Finally, experience suggests that PRP-conducted cleanup can probably be done at lower costs than when undertaken by the government. This, in turn, suggests that a party should give serious consideration to participating in the ultimate remedy.

STRATEGY FOR THE INDIRECTLY LIABLE PARTIES

Parties such as insurance companies, banking institutions and successor corporate owners must realize that Superfund type laws can reach out at any time and embrace them in a web of financial exposure even though they have not been directly involved in the generation, transportation or disposal of hazardous substances.

First, these parties should realize that court decisions are pointing in the direction of holding them responsible as "operators" of Superfund sites where their involvement in day to day management has been pervasive. Furthermore, these parties should be aware of the substantial hurdles for escaping landowner liability at a Superfund site that are contained in the 1986 amendments.

Second, such parties should put themselves in a position to identify sites that are to be considered "suspect" or businesses that may be considered suspect because of the types of materials they deal with. For example, these parties will want to maintain a current copy of the NPL of sites, to obtain from the U.S. EPA a list of sites on a state-specific basis which have been surveyed by the U.S. EPA's FIT for Superfund consideration and/or to obtain a list of parties who have notified the agency that they have generated sufficiently reportable quantities of hazardous substances pursuant to the reporting requirements of Superfund. Such listings are publicly available. At a minimum, these listings can form the basis for intelligent inquiry of an industry on the list by someone who might wish to do business with them.

Third, "indirectly responsible parties" should seriously consider

site investigations by qualified consultants before acquisition is made of any "suspect" site, before a loan is granted to a business operating such a site or before a mortgage interest is taken on such a site. By obtaining this information, these parties will be in a better position to make decisions based on an intelligent analysis of the risk involved. CONCLUSION

The prospects for liability under Superfund and its state counterparts can stagger the imagination. Nevertheless, there are measures which can be employed to avoid, minimize or, if nothing else, manage the problem. This presentation has discussed some of these measures.

Selecting PPE — "I Haven't a Thing to Wear"

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The use and transport of hazardous materials is ever increasing, and more and more formerly "benign" substances are being included in this group. Yet recent Congressional studies estimate that, at best, only about 25% of haz-mat responders are adequately trained. One glaring inadequacy in their training is in their inability to protect themselves from the effects of a hazardous materials incident or, in fact, to protect themselves from their protective equipment! One very knowledgeable haz-mat responder has written, "Protective Ensembles May Be Potentially More Hazardous Than the Incident."

But personal protective equipment is the only practical protective measure available if we are to continue to respond to spills and releases.

Selection of safe and effective chemical protective clothing and respirators is a complex task, made ever more difficult by the exigencies of a spill or accidental release. Proper selection of protective equipment requires balancing the often conflicting demands of numerous factors. Among these factors are the environment to which the worker is exposed, the operating characteristics of available equipment, the task to be performed and the limitations imposed by the human body.

Protective equipment severely limits the performance of a task and imposes significant additional stress on the wearer. Protective equipment, in turn, is limited by the environment, the task, the wearer, and its own design and construction. The perfect ensemble does not, and cannot, exist. Every use requires compromises and tradeoffs such as duration for weight, effectiveness for thermal stress or protection for cost.

In order to assist the haz-mat responder in making these decisions, NIOSH has developed a selection algorithm published in "Personal Protective Equipment for Hazardous Materials Incidents: A Selection Guide," (NIOSH 84-114). This algorithm also is available as a floppy disc for IBM compatible microcomputers (PCs).

A brief study of each of the major classifications of selection factors will serve to illustrate the need for some type of structured aid to decision-making.

ENVIRONMENTAL FACTORS

The Chemical Exposure

- Materials or classes of materials
- State(s)
- Dispersal.
- Quantity or concentration

- Flammability—explosivity
- Radioactivity
- · Sensitivity to shock
- Toxicity and "safe limits"
- Route of entry
- Vapor pressure

The Site Conditions

- Slope
- Terrain
- Temperature
- Relative humidity
- Radiant heating
- Oxygen concentration

Available Equipment

- Chemical resistance
 Permeation
 Penetration
 Degradation
- Field protection factors
- Service life
- Weight
- Encumbrance

Task

- Special hazard such as fire fighting
- Required workrate
- Required mobility
- Distance to exposure

Human

- Weight
- Conditioning

Laboratory and field tests as well as practical experience in the use of this algorithm have demonstrated usefulness as an aid to decision-making. No algorithm or computer program should be expected to replace the professional judgment required of a hazmat responder. This algorithm can assist in logically and concisely requiring consideration of, and decisions on, the key selection factors and thereby lead to more effective selection and use of protective equipment.

(Copies of the program are available as "PREMENU" from the author.)

Health, Safety and Training Requirements For Hazardous Waste Site Workers

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INTRODUCTION

Federal regulations and guidelines including recent "Right-to-Know" legislation have emphasized the need to develop and implement comprehensive health, safety and training programs for hazardous waste site (HWS) workers. Although some of these regulations and guidelines are not specifically aimed at HWS workers, they represent current regulatory intent. Due to implicit liabilities, firms involved in HWS operations must be cognizant of regulatory intent; they also must have the foresight to have state-of-the-art in terms of health, safety, and training programs. This is particularly true in light of OSHA's announced intent to audit Superfund sites for compliance with health and safety regulations via a National Special Emphasis Program, along with statistics that show that the accident/injury rate for HWS workers is 2.5 times greater than for manufacturing industry workers. Also, the U.S. EPA's current concerns regarding "Community Right-To-Know" for residents who live in the proximity of HWS operations further underscores the need for health and safety trained field workers.

This seminar presents an overview of a comprehensive health, safety and training program aimed at HWS field workers.

APPLICABLE REGULATIONS AND GUIDELINES

OSHA Safety and Health Standards (29 CFR 1910 and 29 CFR 1910/1910) are the major, legally binding standards that apply to HWS workers. Noncompliance with these regulations can result in fines and citations. Portions of the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 300) also apply. These documents, however, do not provide adequate guidance in terms of establishing an effective health, safety and training program. The best guidance available is from two documents: "Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities" (NIOSH/OSHA/USCG/EPA, Oct. 1985) and Standard Operating Safety Guidelines (U.S. EPA, Nov. 1984)__

HEALTH, SAFETY AND TRAINING PROGRAM MANAGEMENT STRUCTURE

An important concept in understanding the program's management structure is that safety management is similar to QA/QC management; it must be distinctly separate from site operations management. The program Health and Safety Manager (HSM) must have absolute authority to halt site operations and to prohibit workers from participating in site activities because of safety deficiencies. The HSM should be certified, e.g., CIH or CSP, be experienced in hazardous waste activities, be required to report directly to a senior officer of the firm and be on 24-hr call. Each site should have a Site Health and Safety Coordinator (SHSC) who reports to the HSM and has authority to halt site operations until the HSM can resolve the conflict. Large programs may require a Regional Health and Safety Supervisor (RHSS) with intermediate authority between the HSM and SHSC. The HSM and RHSS must make frequent site audits and train workers on a regular basis.

MEDICAL AND EXPOSURE INJURY SURVEILLANCE PROGRAM

All HWS workers must be certified, by a licensed physician, to be medically qualified to perform hazardous waste site activities and to use respiratory protective devices to perform hazardous waste site activities. This involves medical examinations on an annual basis, following an exposure or injury, after continuous field assignment of 6 months, upon employment termination or upon the request of the worker, the HSM or the physician. Examination protocols vary (some protocols appear in the publications mentioned above), but OSHA regulations require that the physician modify the protocol in order to certify individual workers.

Current medical opinion is that HWS activities may pose a risk of harm to the unborn children of HWS workers unless protective measures are taken. This protection involves restricting field participation of workers who are pregnant or actively trying to conceive. Worker counseling is required to make this aspect of the medical program effective, as it must be based on mutual trust, understanding, sharing of information and cooperation between the employee and employer.

All injuries and exposures that occur on a waste site, no matter how small or seemingly insignificant, must be reported immediately to the HSM. Exposures are difficult to quantify, but all potential exposures should at least be discussed with the HSM. Workers should be required to submit, on a monthly basis, an exposure report summarizing the sites that they have worked on, any exposures or injuries and, most importantly, any observations or occurrences that indicate health and safety violations or deficiencies. The report is confidential and allows the HSM to monitor program effectiveness.

RESPIRATOR, PROTECTIVE CLOTHING AND MONITORING PROGRAM

Workers must be provided adequate respirators and other types of protective clothing. Respirator fit tests must be conducted by certified (by the HSM) respirator fit examiners on an annual basis after facial/dental surgery or after 10 lb weight gain/loss. Protective clothing must be adequate to protect against the anticipated hazards but not too restrictive or excessive as to present a hazard to workers. Safety monitoring (e.g., air, and heat/cold stress) normally is conducted by the SHSC, with frequent reports to the RHSS or HSM. The HSM normally approves site respiratory protective clothing and monitoring equipment requirements as part of the site safety plan.

BASIC HEALTH AND SAFETY TRAINING COURSE

No worker (including subcontractors) can be allowed to participate in HWS activities until he/she has been trained to conduct those activities commensurate with the degree of anticipated hazards. This preparation normally involves providing basic health and safety training, as well as on-the-job training, periodic refresher training, site specific training and first aid/CPR training. CERCLA requires that workers receive a minimum of 5 days (40 hours) of preassignment basic training, followed by a minimum of 3 days of on-the-job training under the supervision of a trained, experienced supervisor. Experience has shown that this initial training needs to be supplemented with first aid/CPR training and followed by continued on-the-job, refresher, and site specific training. Supervisors require the basic course and at least 1 day (8 hours) of specialized hazardous waste site management training.

- Levels of Protection. The U.S. EPA has adopted a comprehensive system for specifying what type of protective gear is to be worn based on four levels of protection: A, B, C and D. The equipment that is used for each level and selection criteria are discussed.
- Hazard Recognition and Evaluation. Workers are exposed to physical, chemical and biological hazards. Regulations mandate that personnel be able to recognize these hazards. Instruction dwells on recognition by stressing thinking before reacting; common sense is the key. The bottom line is if personnel feel unsafe, the task is to be delayed until a sound approach has been devised. Personnel are taught to be rational in their approach to hazards and to know when to seek expert advice. Merely defining the hazard is not sufficient. The significance of the hazard in field operations is of importance.
- Personnel Exposure Standards/Guidelines. Exposure standards/guidelines for toxic, explosive, radiation, noise and heat/cold stress hazards are discussed. The implications of the guidelines and the fact that many are recommendations based on assigning safety factors to the expected reaction of "normal" humans under "normal" conditions should be stressed. Field conditions may drastically alter the guidelines. The key is educating workers to recognize when they need an expert to develop new guidelines and when they can rely upon preestablished ones.
- Sources of Information/Hazard Recognition (Problem). Workers need health and safety data to assess hazards. An introduction detailing the advantages and limitations of various information sources is presented, followed by a hazard recognition problem in which workers develop hazard fact sheets.
- Monitoring Instruments (Workshop). Workers use monitoring equipment to characterize sites, determine level of protection and estimate community impact. Instruction in the actual use of available equipment is provided. Standard operating procedures, calibration, maintenance, data reporting and interpretation, and "action" levels based on exposure guidelines are stressed.
- Heat/Cold Stress. Heat/cold stress is one of the most severe hazards that workers face. Workers are instructed in how to recognize, manage and monitor heat/cold stress.
- Protective Clothing. The basic gear provided to workers is

discussed and demonstrated, including limitations, maintenance, storage, disposal and guidelines for determining when the clothing is no longer usable.

- Respiratory Protection (Introduction and Use) (Exercise). Workers are instructed on the use, cleaning, maintenance, storage and troubleshooting of specific types of respiratory protective gear. A qualitative fit test is performed, and the theory of respiratory protection, selection criteria and physiological/ psychological restrictions is discussed. Workers participate in exercises that simulate field conditions.
- Work Zones and Decontamination (Demonstration). Critical to the safe completion of field activities are work zones and decontamination. Although each site has a unique approach, uniform procedures are emphasized. A standard Level B/C decontamination setup is demonstrated.
- Health and Safety Plans (Exercise). Workers prepare a Health and Safety Plan that is used in the field exercise.
- Field Exercise. An exercise in which workers practice the concepts mentioned in the lectures is conducted. A Team Leader, a SHSC and a Work Crew are designated; tasks and goals are assigned. These tasks include, for example, sampling or collecting air samples. Workers operate available equipment and setup various site situations such as decontamination and work zones.
- Personnel Protection and Safety (Problem). A problem is presented based on the Health and Safety Plan and the field exercise in which participants are required to make field related safety decisions.
- Certification Examination. An examination is given that measures each worker's ability to conduct field activities in a safe manner. The results and the individual's overall performance in the course are used to assign site/activity certification.

ON-THE-JOB AND REFRESHER TRAINING

The most relevant and cost-effective training for HWS workers is on-the-job (OJT) training. This is a system where less experienced workers participate in actual field work with more experienced workers. Also, workers can gain experience in higher levels of protection while working on lower level sites, i.e., wearing Level B on a Level D site. In this way, the impact of a mistake is much less, and workers gain valuable experience. Refresher training in key subject areas (such as respirator use) is conducted on a routine basis.

SITE-SPECIFIC TRAINING

Site-specific training is a requirement for all HWS workers, including subcontractors. This type of training is usually in the form of a briefing at the startup of site work. Topics generally include a discussion of: the Health and Safety Plan; the nature of site specific hazards; safety related duties; site work zones; handling emergencies; emergency contacts, e.g., medical; rules and regulations for vehicle use; dealing with third parties, e.g., visitors and the press; and using equipment. Workers also practice specific site procedures, such as contamination.

WORKER CERTIFICATION

Upon fulfillment of the medical surveillance, training and respirator fit test requirements and successful completion of the certification examination, workers are certified to perform HWS activities at either Level A, B, C or D. The HSM normally provides the written certification. Also, depending upon the experience and training level, workers are certified to either "supervise" HWS activities (-S designation) or "train" under supervision (-T designation). For example, workers certified to supervise Level C operations would carry a C-S designation. First aid/ CPR certification is a requirement for all -S designations.

HEALTH AND SAFETY RECORDS

Worker certification data and exposures/injuries should be tracked on a computerized data base. The data base printout is the controlling document in terms of authorizing workers to perform site work. Note that OSHA requires storage of health records for 30 yr beyond the workers employment; therefore, hard copies of all records and data entries need to be archived.

SITE HEALTH AND SAFETY PLAN

Each site must have a health and safety plan establishing requirements for protecting the workers during all site activities. The plan outlines all health and safety related procedures for the site, specifies protective gear and monitoring requirements, and supplies crucial right-to-know information to the worker. The major elements of the site safety plan include a discussion of:

- Chemical Hazards—Wastes known or thought to have been disposed, along with previous sampling results.
- Physical Hazards—Site specific physical hazards such as unsafe footing, safety lines, test pit cave-ins, heat/cold stress, noise or sharp objects.
- Other Hazards—Other hazards such as radiation, biological or hospital wastes.
- Task Description—The location, schedule, level of protection and specific techniques.

- Protective Equipment—Protective clothing associated with each task and level of protection.
- Monitoring Equipment and Action Levels—The program that will be implemented to monitor site hazards, including "action" levels.
- Site Organization and Control—Work areas (exclusion zone, decontamination zone and support zone), access control points and site security procedures.
- Decontamination Procedures—Procedures for personnel gear, sampling and heavy equipment, including arrangements for the proper disposal of contaminated materials.
- Site Personnel and Safety Responsibilities—Key personnel responsible for site safety.
- Site Emergencies—Actions to be taken and contacts to be made in the case of an emergency.

CONCLUSIONS

A comprehensive health, safety and training program for HWS workers has been outlined. The elements discussed include program management, medical and exposure/injury surveillance, a respirator program, a protective clothing program, site safety monitoring, training, worker certification, maintenance of health related records and the use of site specific safety plans. Compliance with these requirements ensures that HWS workers are provided with a safe working environment and that individual firms meet federal health and safety regulations.

1986 Exhibitors

ATEC Associates, Inc. 1268 North Cobb Pkwy. Marietta, GA 30062

404/427-9456

ATEC Associates, Inc. is a diversified engineering firm with a staff of over 700 in 28 offices located in principal cities throughout the United States. ATEC's Environmental Services Division provides environmental consulting and remedial action services that include environmental audits, RCRA permitting, remedial investigations/feasibility studies, underground storage tank management, asbestor surveys, landfill design, monitor/recovery well design and installation, complete analytical laboratory capabilities, geophysical testing, solid/hazardous waste clean-up, in situ biological treatment and asbestos abatement.

Acres International Corporation

424 Main St. Suite 1000 Liberty Bldg. Buffalo, NY 14202-3592

716/853-7525

Acres International Corporation, 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 treatment systems and remediation programs; and facility closure planning.

Aero Vironment Inc.

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Alchem-Tron, Inc.

7415	Besse	mer	Ave.	
Cleve	land	OH	44127	

216/441-5628

Alchem-Tron, Inc. is an industrial waste disposal/treatment/transportation and reclamation facility. It has been in existence for over 8 years. We are a licensed facility operating at two locations and serving most of the eastern United States. Alchem-Tron offers its customers a complete service package: disposal and transportation of hazardous waste as well as analytical services, consulting and clean-up services. Our staff is Professional.

Alliance Technologies Corporation

213 Burlington Rd.

617/275-5444 x4014 Bedford, MA 01730

RCRA/CERCLA-related remedial engineering, field sampling, laboratory analysis and groundwater monitoring and modeling. Mobile hazardous waste 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 Hygienists. AIHA Certified Laboratory.

Alternative Technologies for Waste, Inc.

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213/929-8103 ATW, Inc. is involved in the development of technologies to provide permanent solutions for the remediation of hazardous waste. Through license agreements, Calweld, Inc. and Toxic Treatments, Ltd. have acquired the rights to manufacture, use and exploit the technologies which currently include equipment and processes for: in situ detoxification of various subsurface and surface contaminated wastes: in situ detoxification of various hazardous waste sites; on-site treatment of generating waste at the producing facilities.

American Fly Ash Company

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312/297-8811

American Fly Ash has over 40 years experience in ash marketing and handling. Serving 15 utilities from more than 30 sources in the central and northeastern United States we can provide Class F and Class C fly ash for waste stabilization or solidification applications.

Aqua-Tech Environmental Consultants, Inc. 181 S. Main St.

Marion, OH 43302

614/382-5991

215/825-3800

Aqua-Tech Environmental Consultants, Inc. (ATEC) was incorporated Oct. 1, 1978 and chartered by the State of Ohio on Dec. 18, 1978 for the purposes of testing, analysis and assessment of aquatic and terrestrial environmental conditions, with recommendations for correcting pollution-related problems. Aqua-Tech is equipped to provide a broad range of analytical services to its clients which consist of industries, municipalities, government agencies and private individuals.

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BONDICO, Inc. has introduced a 90-gallon container system designed for transportation, storage, treatment and disposal of hazardous materials and low-level radwastes. A dual laminate composite of polyethylene and fiberglas, the container provides superior safety and extraordinary cost-effectiveness with multiple reuse, in the hazardous waste market. For radwaste, as a 7A type A package, BONDICO's system provides benefits and performance that will set new standards. This unit may be utilized as a salvage container, on-site storage, transfer container, tool crib or as an encapsulate via its innovative on-site sealing system. BONDICO's container with its fully removable lid, is rustproof, leakproof, corrosion resistant, lightweight, nestable and reusable.

Battelle Pacific Northwest

Laboratories P.O. Box 999

Richland, WA 99352

509/375-2867

Battelle Pacific Northwest Laboratories offers a wide variety of R&D and technical application services including site characterization and assessment for active and inactive sites, health effects assessments, and process control and remediation technologies. Battelle offers advanced technology coupled with a cost-effective, multi-disciplinary approach for solving waste-site cleanup problems.

Beelman Truck Company

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Beelman organization one of the largest bulk carriers in the midwest specializing in transporting hazardous materials. 300 + late-model, weight efficient units with trained personnel assure dependable service-competitively priced. Dumps, tanks, flatbeds and vans available to handle bulk and containerized shipments.

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Beltran Associates, Inc. manufactures electrostatic precipitators and heat exchangers. Beltran's tubular electrostatic precipitator (ESP) is used for the collection of the sub-micron particulates generated in solid and liguid waste incinerators. It is the only ESP on the market which will collect particulates, HCl, SO₂, and acid mist in a single vessel. Various construction materials are ávailable, including conductive FRP. Air-to-air and airto-water heat exchangers are available for the extraction of heat from particulate-laden exhaust gases.

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Bird Environmental Systems, Inc.

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S. Walpole, MA 02071 617/668-0400

Bird Environmental Systems, Inc. will be displaying its new concept for its mobile waste dewatering plants which includes total support such as laboratory facilities to analyze waste streams, 24-hour service, parts and repair, on-site technical support and purchase, lease or rental financing packages available.

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913/339-2000

800/845-5037

716/873-4200

A nationwide consulting firm providing complete engineering services pertaining to hazardous waste management including remedial investigations, feasibility studies, design of remedial actions, oversight of remedial actions, RCRA services, regulatory and permit support, and litigation assistance. Other specialties include waste treatment, waste-to-energy systems, public health evaluations and facility closure services.

Bryson Industrial Services, Inc.

411 Burton Rd. Lexington, SC 29072

Bryson Industrial Services, Inc. is a hazardous waste management company. We provide consultation and management services to customers on methods of reducing, handling and disposing of their hazardous waste. In addition, we provide secure permitted transportation and fully trained and experienced project teams for onsite service needs.

CECOS International, Inc.

2321 Kenmore Ave. Buffalo, NY 14207

CECOS International, Inc., is a company specializing in the treatment and disposal of hazardous chemical waste. CECOS makes these services available to industry through a network of regional treatment centers across the United States and Puerto Rico. CECOS offers specialized hazardous waste capabilities, research and analytical and consulting services.

CH2M HILL, Inc.

P.O. Box 4400 Reston, VA 22090

703/471-1441

412/787-6700

617/742-5151

CH2M HILL is a consulting engineering firm with over 40 offices throughout the world. With extensive experience in hazardous waste site investigations and cleanup, CH2M HILL provides services to both public and private sector clients. CH2M HILL is the primary contractor to U.S. EPA for Superfund sites in the western United States.

Calgon Carbon Corporation

PO Box 717

Pituburgh, PA 15230

Calgon Carbon Corporation supplies activated carbon products, systems and services, and air strippers to remove soluble organic compounds from contaminated groundwater, surface water or waste water.

Camp Dresser & McKee One Center Plaza

Boston, MA 02108

CDM provides comprehensive engineering and management services to public and private clients. Our hazardous waste services include remedial investigations. feasibility studies, site cleanup management, RCRA permitting, computerized groundwater modeling, aquifer restoration, risk assessment, underground storage tank evaluation and remediation, environmental audits, waste reduction and expert testimony.

CarbonAir Services, Inc. P.O. Drawer 5117 Hopkins, MN 55343

612/935-1844

CarbonAir Services provides treatment design and installation for system removal of vapor or aqueous phase organic contaminants in groundwater, surface water or air process streams. Treatment alternatives include Carbon Adsorption, Packed Column Airstripping, and/or any ancillary equipment such as multi-media filtration. Emphasis is on system design and turnkey installation.

Carnow, Conibear and Associates, Ltd.

111 W. Wacker Dr.

Chicago, IL 60606

312/782-4486

Carnow, Conibear and Associates, Ltd., with offices in Chicago, Washington, D.C. and Los Angeles, provides consulting services to address occupational and environmental health concerns associated with hazardous waste. CCA evaluates health effects due to exposure to hazardous substances, designs and implements medical surveillance programs, provides medical exams, trains employees, develops and implements site safety and health plans, offers industrial hygiene services and expert testimony.

Central Mine Equipment

6200 North Broadway St. Louis, MO 63147

Central Mine Equipment Company manufactures drill rigs and drilling tools for geo-exploration and monitoring well installation: high torque multi-purpose augercore-rotary drill rigs, hollow-stem and continuous flight augers, rotary and core drilling tools, soil sampling and testing tools.

Century Laboratories, Inc.

P.O. Box 248 1501 Grandview Ave.

Thorofare, NJ 08086

609/848-3939

314/381-5900

Century Laboratories is an independent environmental testing laboratory providing Priority Pollutant, RCRA, water and wastewater and hazardous waste analysis. Century is equipped with state-of-the-art instrumentation including GC/MS, GC, Atomic Absorption, ICP and HPLC capability. Field sampling and sample pickup services are also available.

Chemfix Technologies, Inc.

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Clean Sites, Inc.

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CSI is the independent, non-profit organization helping to speed the cleanup of hazardous waste sites. It provides assistance in achieving private party settlements, prepares and reviews cleanup plans and manages cleanups. The integration of these services reduces the cost of cicanup.

Combustion Engineering 1515 Broad St.

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Combustion Engineering announces a new business unit, Environmental Systems and Services, to serve the growing environmental market. Through it, C-E provides full environmental consulting services, hazardous site cleanup capabilities and the systems necessary to address hazardous waste issues in the public and private sectors.

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Research Triangle Park, NC 27709 919/549-8263 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; and waste site screening. Among CompuChem's clients are the U.S. EPA and many of the largest consulting engineering firms and industrial corporations in America.

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Converse Professional Group: Converse Environmental East; Converse Environmental Consultants California. Converse offers a broad range of geologic and engineering services to solve environmental problems and regulatory compliance issues relating to groundwater contamination and aquifer restoration. Additional environmental services include hydrogeological and underground tank investigations.

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DART

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DART is a multiservice organization, with its origins in the transportation business. Serving all 48 continental United States, DART is also one of the nation's largest hazardous waste haulers, providing over 300 pieces of equipment, including dump trailers, flatbeds, drop deck vans, bulk pneumatics, etc. DART also serves as a transportation broker, energy broker and services the environmental industry with distribution of sorbents, solidification material and IBM-compatible software that tracks hazardous material and wastes, generating a printed manifest.

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518/783-8102

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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.

EBASCO Services Incorporated 160 Chubb Ave.

Lindhurst, NJ 07071

201/460-6485 EBASCO Services Incorporated is a full-service consulting, engineering and construction company offering toxic materials, hazardous and mixed waste management service. These services include remedial investigations, feasibility studies, chemical and environmental engineering, geotechnical and geohydrological consulting, project management and construction, environmental planning, consulting and design, quality assess-

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On-site hazardous and toxic waste management company specializing in providing the most advanced technological solutions for the on-site treatment of hazardous and toxic waste.

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302/774-2692

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501/375-8444

The company provides integrated hazardous waste management services to private industry, public utilities and governmental entities. These services include chemical analysis, collection, transportation, storage, processing and incineration of hazardous waste. The company also provides transformer decommissioning and other waste management services, including the reclamation of abandoned or problem waste sites, and engineering and construction services for itself and others. The company has developed and is currently marketing modular incinerators for use at hazardous sites.

ENSECO 5530 Marshall St. Arvada, CO 80002

303/421-6611 ENSECO, Inc. provides nationwide laboratory services from facilities in Boston, MA; Berkeley Heights, NJ; Richmond, VA; Houston, TX; Denver, CO; and Sacramento, CA. ENSECO specializes in providing consultative analytical chemistry and aquatic toxicology services to solve environmental problems for industrial clients and governmental agencies. The corporation also has capabilities in industrial hygiene, pharmaceutical chemistry, gas analysis and industrial problem solving.

Earth Resources Consultants, Inc.

P.O. Box 16961 Orlando, FL 32861 305/295-8848 Earth Resources Corporation (ERC) is a full service

hazardous materials management firm specializing in the containment, treatment and removal of all types of hazardous materials. ERC has a highly trained professional and technical staff experienced in the design and implementation of innovative solutions to today's waste problems. ERC's remedial action capabilities include but are not limited to soil, groundwater, facilities, containerized wastes and pressurized gas cylinders.

The Earth Technology Corporation

3777 Long Beach Blvd. 213/595-6611 Long Beach, CA 90807

The Earth Technology Corporation offers comprehensive hazardous waste management services. Those which we are most frequently requested to provide include: environmental auditing/compliance assessment, hazardous waste permitting, remedial investigations, remedial/corrective action, design and engineering, geotechnical investigations, waste stream reduction and recovery, facility closure and laboratory and special technical services.

Ecology and Environment, Inc.

P.O. Box D Buffalo, NY 14225

E & E offers the complete range of hazardous waste engineering and technical services: site investigations; remedial plans and specifications; construction management; hydrogeological studies; groundwater, surface water and air monitoring, etc.; RCRA compliance auditing; underground storage tank management programs; asbestos programs; emergency spill response services; analytical laboratory services. E & E has offices from coast to coast and in 14 foreign countries.

Eldredge, Inc.

898 Fernhili Rd. West Chester, PA 19380

215/436-4749

716/632-4491

Eldredge, Inc., provides the services of waste management, transportation and environmental contracting which include a diversified fleet permitted in 17 states, project management, pollution abatement programs, and cleanup/restoration of industrial waste sites.

Engineering-Science

57 Executive Park South, NE Atlanta, GA 30329

404/325-0770

Engineering-Science (ES) is a major, full service, national and international environmental engineering firm providing complete services in hazardous waste management. ES has offices in 15 domestic locations conveniently located to serve industry, military and governmental clients. ES is active in supporting industrial and military clients in all phases of site/remedial investigations, feasibility studies, remedial action plan preparation, site cleanup/closure and post-closure activities.

Enviresponse, Inc.

110 S. Orange Ave. Livingston, NJ 07039 201/533-2385

Enviresponse, Inc., contractor for the U.S. EPA's Environmental Emergency Response Unit in Edison, NJ. offers a wide range of technologies and expertise relevant to the complex problems surrounding the treatment of hazardous and toxic waste. Services range from con-

Envirite Field Services, Inc.

600 W. Germantown Pk., #221

Plymouth Meeting, PA 19462 215/825-8877

sulting to design and construction. Enviresponse, Inc. is

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Envirite Field Services provides solidification/fixation services for organic and/or inorganic industrial wastes. The company offers three proprietary delivery systems to stabilize waste liquids, sludges and contaminated soils

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Environmental Management News, a bi-monthly newsletter reaching environmental managers responsible for the management and control of air, water, wastewater, pollution and hazardous materials.

Occupational Health and Safety Magazine, a monthly publication reaching over 92,000 Safety Managers, Industrial Hygienists, Occupational Physicians and Occupational Nurses.

Environmental Science &

Engineering, Inc.

P.O. Box ESE Gainesville, FL 32602

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.

Environmental Technology Inc.

Second and Maury Sts.

Richmond, VA 23224 804/231-2232 Environmental Technology, Inc. is a diversified environmental engineering firm that supplies geotechnical consulting, environmental engineering, and municipal and industrial services. Services include petroleum, chemical and waste tank evaluation, decontamination, removal and disposal. We also provide site assessment, remedial action alternatives, cost estimates and compliance monitoring closure plans.

Envirosafe Services, Inc.

115 Gibraltar Rd. Horsham, PA 19044

215/441-5924 Envirosafe Services, Inc .- hazardous waste management through a variety of subsidiaries: ACES -Associated Chemical & Environmental Services -provides remedial services, spill cleanups, biotechnology, groundwater filtration, site maintenance, iagoon closures and underground storage tank excavation. Fondency Enterprises, Inc.-disposal services for hazardous/non-hazardous wastes, landfarm capabilities. Environnée Services of Idaho, Inc .---(ESII) secure disposal services for PCB-contaminated materials.

Envirosure Management Corp.

333 Ganson St.

Buffalo, NY 14203 716/854-3611 Envirosure's remedial services begin with careful consideration of total job scope and risk potential in performance of our total project management proposal. Analytical services and procedures become essential to remedial action as ground and surface water quality identification may be required. Effective remedial onsite operations personnel who are experienced and

highly trained in total project management and field supervision. Envirosure's specialty transportation and disposal options coincide and complement one another, as we are able to provide transport vehicles specific to be moved off-site for final treatment and disposal.

Evergreen Safety Systems, Inc.

P.O. Box 1207	303/422-2185
Arvada, CO 80001-1207	800/525-8696

Mobile decontamination units for personal hygiene involving hazardous materials. Standard 6 & 12 person models as well as customized self-contained units which include the negative air concept with HEPA or activated carbon filter. All units are constructed of first class materials and meet or exceed EPA & OSHA requirements.

F.C. Witt Associates, Ltd.

Maple St. Industrial Pk., P.O. Box 128 815/634-8567 Coal City, IL 60416

F.C. Witt Associates Ltd. manufactures corrosion resistant liners for tanks, pits, floors and trenches, and small ponds. Materials are resistant to acids, alkalines, U.V. and hydrocarbons. All liners are custom fabricated. One to two day emergency service available.

Federal Ore & Chemicala, Inc.

117 Fifth Ave.

Belle Fourche, SD 57717

605/892-2743

A major producer of western sodium bentonite clay used as a containment material for toxic and hazardous wastes. Federal Bentonite has been used in slurry trench cut-off walls, landfill and lagoon linings and tank farm impoundments to provide an extremely low permeability barrier. The products include Ultra Seal*, Slurry Mud[®] 90 & 125, Marine Seal[®], PPS and Akwaseal[®]

The Foxboro Company 151 Woodward Ave.

904/332-3318

South Norwalk, CT 06856

203/853-1616

Instrumentation for providing quantitative and qualitative information on hazardous waste and spill site contaminants. The instruments can be used at the waste site to locate areas of high vapor concentration, to identify and determine concentration levels of various organic compounds, and to provide rapid, reliable field screening/analysis for volatile hydrocarbons in groundwater samples.

Froebling & Robertson, Inc. 3015 Dumbarton Rd.

Richmond, VA 23261

804/264-2701

Froehling & Robertson offers the services of professional engineners, chemists, construction inspectors, geotechnical engineering and drilling. Capabilities include: preliminary assessments, site investigations, RCRA studies and monitoring programs, landfill projects, etc.

Faltz Pumps, Inc.

P.O Box 550 Lewistown, PA 17044

717/248-2300

Small Diameter Sampling Pump. Fultz Pumps, Inc. is the manufacturer of 114" diameter and 214" diameter stainiess steel and teflon[®] sampling pumps. The pump units are complete with 100' vinyl hose (teflon® available), 24V power system, charger and lightweight backpack. The complete units are one-man operable and very portable. Optional equipment available.

GA Technologies

P.O. Box 85608 San Diego, CA 92138

619/455-3353

Circulating bed combustor systems. Circulating bed technology has been used to destroy a variety of hazardous solids, liquids, sludges and slurries, including PCBs in soil, refinery wastes and pesticides. U.S. EPA requirements for RCRA & TSCA materials are met without the use of wet scrubbers or afterburners.

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, hydrogeologic investigations, site selection and cost optimization evaluations, and site operation and closure plans.

GSX Chemical Services, Inc. 121 Executive Center Dr., #100

Columbia, SC 29210 803/798-2993

Principal lines of chemical waste business are high temperature incineration; secure chemical landfill operation; chemical waste collection and transfer; emergency remedial and technical services. From its facilities in Maryland, North Carolina, South Carolina and Tennessee, GSX provides a full range of analytical, administrative and transportation services to ensure regulatory compliance by its customers. In S.C. GSX owns the largest commercial liquid waste incinerator in the southeast designed to destroy a wide range of liquid waste streams. Also in S.C., GSX operates one of the nation's largest secure chemical landfills. It meets all new, stringent federal regulations. In N.C. GSX's Emergency, Remedial and Technical Response Group is one of the primary response units for chemical spills and cleanups in that state. The group provides nationwide remedial services to private industry, including analysis, development of cleanup plans, decontamination of buildings and equipment, handling of explosives, landfill closure and the cleanup of storage tanks and surface impoundments. In addition, the group provides services for the disposal of household hazardous wastes.

Geo-Con. Inc. P.O. Box 17380

Pittsburgh, PA 15235

Geo-Con is a full-service construction company that specializes in the containment, removal and stabilization of all types of hazardous wastes. With an extensive background nationwide in hazardous waste remedial work and the construction of new containment systems, Geo-Con offers owners and consulting engineers experience and expertise that is unique in the industry.

GeoSyntee, Inc. 3050 SW 14th Pl. Boynton Beach, FL 33435

305/732-9910

412/244-8200

GeoSyntec is an independent plastics testing laboratory staffed by experts in materials science, plastics engineering and polymer chemistry. The company is dedicated to the forensic analysis, research and development and testing (conformance, quality control, mechanical, chemical compatibility and hydraulic properties, etc.) of geosynthetics, including geomembranes, geotextiles, geonets, geogrids and geocomposites used in landfill and impoundment systems.

GeoSyntec's facilities consist of mechanical, physical, hydraulic and chemical testing laboratories.

Geonics Limited

1745 Meverside Dr., #8 Mississauga, Ontario Canada L5T 1C5 416/676-9580

Geonics Limited, a world leading manufacturer of electromagnetic geophysical equipment, present their Ground Conductivity Meters EM31, EM34-3 and EM38 with digital data logging system providing a rapid data processing and contaminant plume contour mapping capability. The EM39 Borehole Conductivity Meter provides accurate delineation of the contaminant plume and monitoring capability.

Greenhorne & O'Mara, Inc. 9001 Edmonston Rd. Greenbelt, MD 20770

301/982-2800

Greenhorne & O'Mara, Inc., an engineering design firm, was founded in 1950 by A. James O'Mara and Marcus F.H. Greenhorne (deceased). The company has grown steadily through the years and today provides multidisciplinary services nationally in both public and private sectors. The firm, currently ranked 71st in the United States, has 12 offices and a staff of over 811. Professional services include: architecture, automated information, construction services, earth sciences, land development, landscape architecture, water resources, surveying, photogrammetry, planning, and civil, environmental, structural and transportation engineering.

Groundwater Decontamination System

140 Rt. 17, N., Suite 210 Paramus, NJ 07652

201/265-6727

Introducing Groundwater Decontamination Systems (GDS), the unique new system for soil and groundwater decontamination. The GDS process eliminates hydrocarbon and halogenated hydrocarbon contaminants from groundwater and soil through a process of ac-

celerated biodegradation by micro-organisms existing in the contamianted soil. Patent awarded.

Gundle Lining Systems Inc. 1340 E. Richey Rd. Houston, TX 77073

Gundle Lining Systems Inc. is recognized as the World Leader in the manufacture and installation of High Density Polyethylene lining systems. Gundle manufactures HDPE in 22.5 feet seamless widths from 20 to 100 mil thick. Also, Gundle manufactures and installs Driline and Gundnet Drainage Net for leachate collection systems. For the past 22 years, Gundle Lining Systems has manufactured and installed over 300 million square feet of lining systems using the advanced Extrusion Welding Machine. For more information, call 800/435-2008 or 713/443-8564.

HARCO, Corp. P.O. Box 721

Medina, OH 44258

216/725-6681

800/435-2008

713/443-8564

HARCO Corporation, established in 1948, the recognized world leader in the field of corrosion control and cathodic protection, provides services and materials on a worldwide basis. Full professional engineering, from investigation through design and cathodic protection system maintenance, plus construction services and a complete line of quality materials are available through 15 domestic and 6 international locations. HARCO Corp. World Headquarters, 1055 W. Smith Rd., Medina, OH 44256, 216/725-6681.

Harza Environmental Services

150 S. Wacker Dr. Chicago, IL 60606

Harza Environmental Services, Inc. (HES) provides a broad range of consulting engineering services in the

312/855-5200

management of hazardous and solid waste. Planning and design through construction and start-up are provided for remediation, new facilities, and facility expansions. As a wholly-owned subsidiary of Harza Engineering Company, this multidisciplinary group of engineers, scientists and technicians develops practical solutions to hazardous and solid waste management problems. Other Harza companies are available to HES when additional expertise is needed.

Hazco, Inc.

1347 E. Fourth St. Dayton, OH 45402

513/222-1277

800-28-SOLID

Hazco is a national turn-key supplier of all the health and safety equipment required to safely respond to a remedial project or emergency haz-mat incident. Services include site specific PPE packages delivered from stock; 24-hour access to our Tech Service via 1-800-332-0435; rental of HNUs, OVAs, instruments, and decon trailers; and our Safety Network Approved Purchasing Plan (SNAP). Our experience is your advantage!

HAZCON Engineering, Inc.

ment.

Katy, TX 77492 713/975-8404 HAZCON, Inc. specializes in solidification of organic hazardous waste and conversion of sludges and fluids into a solid mass resembling concrete. Tests have shown the resultant mass is leach-resistant and practically impermeable. Toxicity is dramatically reduced, and in most cases there is little increase in volume after treat-

HDR Infrastructure, Inc.	
8404 Indian Hills Dr.	
Omaha, NE 68114	402/399-1000

HDR Infrastructure, Inc. specializes in industrial and hazardous waste management, including remedial investigations and feasibility studies of hazardous waste sites; design and implementation of remedial action alternatives; hazardous waste facility permitting; design of hazardous waste treatment, storage and disposal facilities: and closure/post-closure planning for hazardous

waste management facilities. HDR's industrial projects encompass the study, design and implementation of industrial waste treatment, ultra pure water, gas and chemical systems; control of toxic emissions; environmental permitting; and process/process support facilities for high-tech industries.

Hazardous Materials Control Research Institute

9300 Columbia Blvd.

Silver Spring, MD 20910

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!!"

HNU Systems, Inc.

160 Charlemont St. Newton, MA 02161

617/964-6690 Model IS101 portable intrinsically safe photoionization analyzer, GP101 portable general purpose photoionization analyzer, PI101 portable photoionization analyzer, 301P portable compact gas chromatograph, 331 compact dedicated capillary gas chromatograph, 321 compact temperature programmed gas chromatograph.

Hanson Engineers, Inc.

1525 S. Sixth St. Springfield, IL 62703

217/788-2450

301/587-9390

HEI provides environmental/waste management, geotechnical, geological, hydrogeological, civil, hydrologic and structural engineering consulting services to industry and government clients. Services at hazardous waste sites include: site characterization; remedial investigations; feasibility studies; design and supervision of remedial action; hydrogeology studies; impoundment studies, design, plans and construction monitoring; underground tank management-spill control, countermeasure plans (SPCC) and tank retirements; groundwater monitoring, sampling and modeling; stabilization studies; and geotechnical laboratory testing of contaminated soils.

HAZTECH. Inc.

5280 Panola Industrial Blvd. Decatur, GA 30035-4013

HAZTECH, Inc., a hazardous waste cleanup contractor, offers services such as contaminated soil removal, on-site treatment, tank testing and cleaning, lagoon closure, sludge solidification and buried waste and drum excavation. HAZTECH also provides 24-hour emergency spill response, mobile incineration and dewatering services, site assessment and lab pack removal.

Hewlett-Packard Co.

2 Choke Cherry Rd. Rockville, MD 20850

301/921-6296

617/636-8811

302/322-3808

404/981-9332

Hewlett-Packard will exhibit a gas chromatography system for analysis of purgeable halocarbons and aromatics in wastewater and drinking water. The unit consists of a gas chromatograph, purge and trap device, electrolytic conductivity detector and photoionization detector. Also we will exhibit a gas chromatograph/ mass spectrometer for environmental analyses.

Hoyt Corporation

251 Forge Rd.

Westport, MA 02790 Solvent Vapor Recovery/Air Pollution Control Equipment; Distillation Equipment; Odor Control Equipment.

I-Chem Research

104 Quigley Blvd. New Castle, DE

A complete line of sample bottles, jars and vials, supplied with teflon-lined closures attached and available chemically cleaned and treated to exact U.S. EPA protocols. Also available custom-cleaned to your exact specifications. I-Chem Research is supplier of precleaned sample bottles, jars and vials to the U.S. Superfund program nationwide.

ICAIR, Life Systems, Inc.

24755 Highpoint Rd. Cleveland, OH 44122

216/464-3291

ICAIR, Life Systems, Inc. (ICAIR) specializes in human health and environmental effects assessments (endangerment, public health, toxicity, contamination, environmental and risk and impact assessments). ICAIR's uniqueness is in its approach, integrating the experience of ICAIR's core scientific and management staff with the finest scientific and technical minds in the world.

ICF Technology

1850 K St., NW Washington, DC 20006

202/862-1100

ICF Technology-the scientific and engineering subsidiary of ICF Incorporated-consults on environmental and hazardous waste management issues. We provide our clients with a full range of technical services, from site-specific investigations and risk assessments to remedial design and construction monitoring. The firm is headquartered in Washington, D.C.

ICOS Corporation of America

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Slurry walls, slurry trenches, drilling, grouting, bored piles, load-bearing elements, tieback anchors, sewer rehabilitation, shotcrete, Envirowall.

INFORM

381 Park Ave., S. New York, NY 10016

212/689-4040

INFORM is a non-profit research organization that reports on practical actions for the preservation and conservation of natural resources. We conduct seminars, provide speakers for conferences, and are frequently called upon to brief committee's such as the U.S. Senate Environmental & Public Works, and the U.S. House of Representatives Committee on Energy and Commerce. Our research is published in books, abstracts, newsletters and articles in major business, environmental and industry publications.

In-Situ, Inc.

P.O. Box I - 210 S. 3rd St. Laramie, WY 82070-0920

800/4-INSITU

In-Situ, Inc. began as a consulting firm providing computer modeling hydrologic evaluation, and laboratory R&D services in in-situ mining and related energy industries. In-Situ has broadened its technological base to include the development and sale of state-of-the-art hydrologic instrumentation and software, to provide time-sharing services to clients through its Computer division.

Industrial Training Systems Corporation

20 West Stow Rd.	800/922-0782
Marlton, NJ 08053	609/983-7300

Industrial Training Systems Corporation produces and markets audiovisual training programs for industry in the areas of health, safety and the environment. Our library of over 80 slide/tape and live action video programs includes Hazard Communication training, accident prevention, environmental programs and more. Our Training and Consulting Services Department consists of a staff of certified consultants that can provide stand-up training at your location.

Inorganic Ventures, Inc.

P.O. Box 1432 Brick NJ 08723 201/364-3643 Inorganic Ventures provides QC & calibration trace metals standards for EPA, CLP and OSHA protocols.

These standards have been developed by Spectra. Spectra provides on-site training for EPA, CLP and OSHA protocols. Representatives from Inorganic Ventures and Spectra will be present to discuss your specific needs.

Intellus Corporation

3355 Michelson Dr

Irvine, CA 92715

714/975-6000

817/267-3319

Intellus serves both government and industry with a comprehensive range of environmental services including: underground tank services, hazardous material management, environmental engineering, regulatory analysis and permitting, environmental auditing and risk management. Intellus has an extremely broad base of experience, and has completed a multitude of complex study and design projects for clients in manufacturing, natural resources, biotechnology, transportation, petrochemical and many others.

International Chem Pack Corp.

10500 Tube Dr.

Horst, TX 76053-7910

ENVIROPACKTM (DOT-E 9341) Polyethylene Salvage Drum • ENVIROTANKTM (DOT-E 9519) Portable, 250 and 350 Gallon, Polyethylene Shipping Containers with Steel Framework.

International Technology Corporation

23456 Hawthorne Blvd.	209-211
Torrance, CA 90505	213/378-9933

International Technology Corporation (IT) is the nation's premier firm devoted exclusively to the management of hazardous substances and situations. Through 37 offices nationwide, IT serves both government and industry with a comprehensive range of services including analytical; engineering; risk control; decontamination and remedial; and transportation, treatment and disposal.

JWI, Inc.

2155 112th Ave. Holland, MI 49423

JWI, located in Holland, Michigan, manufacturers of process equipment filter presses for solid liquid separation, dryers for volume production of hazardous waste. JWI also manufactures continuous blending equipment for sludge stabilization as well as portable mixers for general mixing application.

Jacobs Engineering Group, Inc.

1511 K St., NW, Suite 1100 Washington, DC 20005

202/783-1560

301/322-5400

616/772-9011

Jacobs Engineering Group, Inc., an international environmental engineering and construction firm, has extensive experience, particularly with respect to the remediation of hazardous waste sites, and provides engineering services to evaluate sites, characterize the nature and extent of contamination, and develop remedial action plan alternatives, including cleanup design.

James T. Warring Sons, Inc. 4545 "S" St.

Capitol Heights, MD 20743

All types and sizes of containers-new and reconditioned-fiber, steel, plastic. Our hazardous waste containers are DOT approved and range in size from 5 to 83 gailons. 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!!

Kramer Environmental

935 Allwood Rd.

Clifton, NJ 07012 201/471-9500, X203

Kramer Environmental, a division of Kramer Industries, provides "total" environmental services. Our comprehensive range of services includes chemical disposal, remedial action, laboratory analysis, drum handling in our new transfer and storage facility (TSDF EPA ID N O. NJD065825341), technical services, and transportation. For more information contact: Kramer Environmental, 935 Allwood Rd., Clifton, NJ 07012, 201/471-9500.

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LEFCO WESTERN pumps sludge!-as a design-builder of material-moving systems such as Sludge Buster and V.A.M.M. These systems have a 100-foot boom reach and are capable of moving up to 80% solids with distances in excess of 5,000 feet. Our pumping systems are self-contained and can be placed almost anywhere.

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Manufacturer of K-20 brand products for the control and prevention of leaching and migration of hazardous toxic substances. For application in soil-like particulate matter and on various cementitious surfaces. The easyto-apply proprietary products are recommended for use in the control of PCBs and other chlorinated organic compounds, and toxic heavy metals-lead, mercury, chromium.

Law Engineering Testing Company P.O. Box 888013

Atlanta, GA 30356 404/396-8000 Law Engineering Testing Company assists clients with their hazardous and nonhazardous waste concerns, specializing in seven core business areas: Hazardous and Solid Waste Management . Groundwater Hydrology and Resource Development . Surface Water Hydrology and Water Quality Protection . Land Treatment of Wastes . Ecological Assessment . Geophysical Exploration • Seismic Hazard Evaluation.

Lawler, Matuaky & Skelly Engineers One Blue Hill Plaza Pearl River, NY 10965

914/735-8300 Lawler, Matusky & Skelly Engineers is an environmental science and engineering consulting firm founded in 1965. LMS offers comprehensive services in waste management and groundwater resource planning including consultation and assistance in developing regulatory compliance programs. LMS provides contamination assessment; preliminary site assessment; field sampling and monitoring for wastes, soils, groundwater and surface waters; remediation design; environmental and risk assessment; modeling and statistical evaluations of data; permit assistance; QA/QC compliance and procedures; oversight services; and other engineering/biological and groundwater services.

Layne-Western Company, Inc. 5800 Foxridge Dr. Mission, KS 66202

913/362-0510

201/383-0800

Layne-Western Company, Inc. provides a fuli range of professional services associated with hazardous waste investigations, remedial actions and site monitoring. Working with consulting engineers, major industrial concerns and municipalities, Layne's trained and experienced personnell can provide expertise with any drilling method, sampling technique and well design. Layne also brings to each project complete site safety plans, quality control and assurance methods and full project documentation.

The Lion Group P.O. Drawer 700 Lafayette, NJ 07848

Tank and Line Compliance: precision certified tank testing. Underground storage tank removal and retrofitting, predictive assessments. Leak prevention, detection and correction. Inventory reconciliation and turnkey tank management systems. Soil and hydrogeological services, cleanups, monitoring systems and contingency plans. Site assessments, training workshops and environmental management systems.

Liquid Waste Technologies, Inc. P.O. Box 282 Blackwood, NJ 08012

609/227-4711 Liquid Waste Technologies offers a line of products for organic stabilization, extraction of hydrocarbons from soil, and oil spill cleanup. Oil Bond-100 reacts with a

wide variety of petroleum and oil-based wastes. It changes the physical characteristics of the waste to that of a solid, it will not revert back to a liquid, or release liquid, under conditions of pressure, water contact, cold or heat within acceptable limits for storage or disposal of the waste.

MAC Corporation/Saturn Shredder Division 201 E. Shady Grove Rd. Grand Prairie, TX 75050

214/790-7800

MAC Corporation's Saturn Shredder Divsion manufactures low-speed, high-torque, rotary shear-type shredders designed to produce required size reduction applications for light metals, ferrous and non-ferrous, plastic, wood, rubber, glass, paper for recycling purposes and provide resource recovery or waste to energy assistance for hazardous, nuclear, municipal or industrial solid waste. Innovative effective systems for proper waste reduction is Saturn's expertise.

MAECORP incorporated Homewood, IL 60430

17450 S. Halstend St.

312/957-7600

MAECORP Incorporated provides all services required in the cleanup of hazardous waste sites and hazardous material (chemical) problems. The services themselves are of a technical problem-solving nature, applied in a "hands-on" fashion. Chemical decontamination of facilities and equipment: hazardous material handling, including pumping, packaging, etc. On-site field chemical treatment, including incineration, detoxification, neutralization, in situ vitrification, fixation, ultra-violet peroxidation, biological degradation, reclamation and groundwater recovery. Hazardous material spill recovery and transportation.

MDS Advanced Analytics, Inc.

Two Dundee Park Andover, MA 01810

617/470-1390

MDS Advanced Analytics, Inc. specializes in mobile analytical services and offers on-site solutions to complex environmental and chemical process monitoring problems. The company is dedicated to providing the highest quality mobile chemical detection and analytical services designed to efficiently solve your monitoring needs.

MSI Detoxification Incorporated 100 Enik Dr.

Bozeman, MT 59715

406/586-4766

MSI Detoxification Incorporated (MDI) is a full-service hazardous waste site detoxification company. MDI's services extend from legal and technical problem definition, to integrated emergency responses/remedial investigations, to feasibility studies based on state-of-the-art analyses of site parameters and alternative technologies, to total site detoxification based on a unique biological technology and complementary technologies which will significantly lower detoxification costs.

MTA Remedial Resources, Inc. (MTARRI) 1511 Washington Ave. Golden, CO 80401

303/279-4255

MTA Remedial Resources, Inc. is a remedial action contractor that provides: safe and cost-efficient execution of remedial action projects • application of alternative technology available today • detoxification of contaminated material on-site or in situ to reduce the volumes requiring handling • reduction of long-term liabilities • recovery of useful or valuable minerals.

Marcel Dekker, Inc. 270 Madison Ave.

New York, NY 10016

Marcel Dekker, Inc. will be displaying new titles including Economic Methods for Multipollutant Analysis and Evaluation (Baasel), Materials Recovery From Municipal Waste (Alter) and Reducing the Carcinogenic Risks in Industry (Deisler) among other new titles. Discount order forms are available at the booth.

Marine Pollution Control 8631 W. Jefferson Ave.

Detroit, MI 48209

313/849-2333 Marine Pollution Control was one of the first cleanup companies in the United States. We have developed into

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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.

Mary Ann Liebert, Inc. Publishers

1651 Third Ave. New York, NY 10128

212/289-2300

Mary Ann Liebert, Inc. publishes journals, books and news publications in the most exciting and new areas of science and medicine. One of the journals, Hazardous Waste & Hazardous Materials, edited by Norman Beecher, Sc.D., is the official journal of the Hazardous Materials Control Research Institute. This journal is the central source of information for advancing technology, providing economical and ecological methodology for the regulation and management of hazardous waste and related hazardous material.

Med-Tox Associates, Inc.

1401 Warner Ave., 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, both generic and site specific are developed. Toxicological risk assessment, medical surveillance and training for hazardous waste site personnel are provided.

Metcalf & Eddy, Inc.

P.O. Box 4043 Woburn, MA 01888

617/246-5200 x4007

Engineers & Planners: Hazardous Waste Management -Program Management - Contract Ops - Privatization -Sludge Management - Water & Wastewater Management - Roads/Bridges - Transportation - Facilities.

Mineral By-Products, Inc.

777 Franklin Rd Marietta, GA 30067

404/424-0247

Mineral By-Products, with headquarters in Marietta, Georgia and offices in Dayton, Ohio and Gary, Indiana, supplies PozzalimeTM from numerous strategic locations. PozzalimeTM is effective for neutralization and meets the RCRA requirements as a solidification material for most hazardous and non-hazardous bulk liquids.

Model Management/Scientific

Publications

P.O. Box 23041 703/620-9214 Washington, DC 20026-3041

There are more than 70 groundwater programs available to analyze groundwater data, store well records in data bases, simulate groundwater flow and well fields and model groundwater contamination. These programs are in use with state and Federal agencies, universities and consulting companies in: Canada, USA, England, Germany, Sweden, Norway, South America, India and they are also used by the United Nations.

Modern Industrial Plastics

3337 N. Dixie Dr. Dayton, OH 45414

513/226-8009

Modern Industrial Plastics will exhibit products for groundwater monitoring made from Teflon®. These products include MIP casing and screen material sold through stocking distributors, a bladder pump made entirely of Teflon with pump controller and a bailer of all Teflon. See us in booth 105.

Morris Industries, Inc.

777 Rt. 23

Pompton Plains, NJ 07444 The Morris Monitor Well Locking Cap is designed to give maximum security. Welded tamper-proof with all heavy gauge steel, it is available in above-ground and flush-mount models. Both will accommodate your own standard security padlock. Popular sizes are in stock.

NAC Northeastern Analytical Corp.

234 Rt 70 Medford, NJ 08055

609/654-1441

201/835-6600

Northeastern Analytical Corp. (NAC) provides technical support for hazardous waste projects. The Field Services Group is experienced in all facets of air/soil/ waste sampling and tank testing. The NAC Industrial Hygiene Group can manage the health and safety program. The laboratory provides complete chemical analysis of site samples.

NUS Corporation

910 Clopper Rd. Gaithersburg, MD 20878

301/258-1299

NUS Corporation, a Halliburton company, offers comprehensive remedial services using proven engineering and planning techniques which ensure health, safety and regulatory compliance. From process control and risk assessment to community relations and emergency planning, our extensive experience means cost-effective solutions. The record: over 2,000 site and field assessments, scores of remedial investigations, feasibility studies and project engineering for problems such as chemical spills, leaking underground storage tanks, sludge pits and landfills. Our staff of over 1,500 specialty engineers, scientists and technicians brings years of on-site experience to government and industry, making NUS a top resource for hazardous waste consulting expertise.

Nanco Labs, Inc.

Unity St. at Rt. 376 P.O. Box 10 Hopewell Junction, NY 12533

Nanco Labs provides quality, cost-effective environmental analyses to clients throughout the United States. Nanco is a contract laboratory to the U.S. EPA, the New York State DEC and the New Jersey DEP. Nanco specializes in HSL, priority pollutant and RCRA analyses.

National Draeger, Inc.

P.O. Box 120 Pittsburgh, PA 15230

National Draeger, Inc., a U.S. subsidiary of Draegerwerk AG, located in Luebeck, West Germany, has earned a worldwide reputation for being the leader in manufacturing specialized equipment and systems which enable, support and protect human breathing safety. By introducing innovative new products for gas detection and warning systems, breathing protection. filter technology, diving equipment, air supplied systems for aviation and space technology as well as medical equipment, Draeger helps to upgrade safety standards for the entire safety industry.

National Environmental Health

Association

720 S. Colorado Blvd., S. Tower Suite 970

Denver, CO 80222 303/756-9090 National Environmental Health Association is a national, nonprofit organization of environmental health professionals who work to control environmental hazards so as to attain optimum human health. Members are employed by federal, state and local

governments, schools, medical care facilities, the military, industries and are educators and students of environmental health.

National Institute for Occupational Safety and Health 4676 Columbia Pkwy.

Cincinnati, OH 45226 513/684-8328

Employees work safely at a hazardous waste site if they are informed of the hazards involved, receive necessary training, follow the proper procedures, use the required personal protective equipment and remain aware of the conditions or situations around them at all times. The NIOSH exhibit includes recommendations for the control of occupational hazards, including the NIOSH Hazardous Waste Sites and Hazardous Substance Emergencies-Worker Bulletin. Information will be available for NIOSH Recommended Criteria, Current Intelligence Bulletins, Technical Reports and our data base.

National Lime Association

3601 N. Fairfax Dr. Arlington, VA 22201

703/243-5463

516/334-7770

The National Lime Association exhibit provides information on the use of lime for hazardous waste treatment. The principal use of lime is the neutralization of inorganic acidic waste and the precipitation of heavy metals. Lime and fly ash form a pozzolanic material which can be used to solidify a hazardous sludge.

Nytest Environmental

75 Urban Ave. Westbury, NY 11590

An independent laboratory providing complete analytical services for the screening and analysis of hazardous waste. The laboratory is equipped with sophisticated computerized GC/MS systems including extensive automated allied instrumentation enabling it to perform analytical programs thoroughly, competently and quickly.

O.H. Materials Co.

16406 US Rt. 224 East Findlay, OH 45840

419/423-3526

Environmental Services: Groundwater Recovery and Treatment; On-site Treatment Equipment; Hazardous Waste Site Cleanup; Facilities Decontamination; Biological Treatment; Technical Advisory Services; Laboratory Services; Emergency Response; Surface Impoundment Restoration; Explosives/Reactives Handling: Underground Storage Tank Management-from response centers in Massachusetts, New Jersey, Virginia, Florida, Georgia, Alabama, Louisiana, Texas, Ohio, Michigan, Minnesota, Missouri and California,

Occupational Hazardous Magazine 1111 Chester Ave.

Cleveland, OH 44114

216/696-7000

A trade magazine serving the industrial safety, health, hygiene and plant protection market.

Orlando Laboratories, Inc.

3444 McCrory Pl., Suite 124 Orlando, FL 32803

305/896-6724

Orlando Laboratories is an analytical laboratory providing services to the public, engineering firms, government agencies, industries and consultants. We endeavor to utilize only the most modern analytical equipment in the analysis of our client's samples. Our expertise includes hazardous waste, facility monitoring and gas chromatography/mass spectrometry confirmation.

OSCO, Inc. P.O. Box 1203 Columbia, TN 38401 615/381-4999

Permitted hazardous waste transporter in 40 states. Over 70 trailers including van, flatbed, roll-off, and acid, flammable and vacuum tankers. LTL available. Hazardous liquid treatment plant in Columbia, TN accepts acids, bases and other aqueous wastes. Complete labora-

914/221-2485

412/787-8383

tory. Lagoon closures and environmental consulting. No assignment too small or too large.

P.E. LaMoreaux & Associates

P.O. Box 2310

Tuscaloosa, AL 35403 205/752-5543

P.E. LaMoreaux & Associates, Inc. (PELA), hydrologists, geologists and environmental scientists, offer hydrological, geological, environmental and hazardous waste consultation services throughout the world. Other services include emergency spill response, sampling, laboratory analysis, development of monitoring programs and installation of wells, reclamation, government permitting, court testimony and graphic and communication programs.

Photovac International Inc.

739B Park Ave. Huntington, NY 11743

516/351-5809

Photovac, the manufacturers of ultra-sensitive air analyzers, will exhibit the new Total Ionizables Present Monitor TIP II which has multilamp capability and is rated for Div. II operation. The recently introduced 10S70 Portable Intelligent PID/GC with built-in modem and RS 232 interface will also be demonstrated.

Planning Research Corp.

303 E. Wacker Dr. Chicago, IL 60601

312/938-0300 PRC, serving both government and industry, has ranked

among the 10 largest engineering firms in the country since 1977. Headquartered in McLean, VA, PRC maintains 50 offices in the U.S. Specialties include remedial investigations/feasibility studies, risk assessments, compliance audits, permitting support, environmental and systems engineering, and program management support.

Pollution Abatement Consultants & Services

800 Orange St. Millville, NJ 08332

609/825-1400 x2560

Manufactures sampling equipment for drums, tanks, surface and groundwaters, sludges and solids. Also provides safety-coated sample containers, sample shipment systems, environmental laboratory kits, apparatus and accessories as well as personal protective equipment.

Poly-America 2000 W. Marshall

Grand Prairie, TX 75051

817/640-0640

Poly-Flex is a polyethylene geomembrane liner (20-100 mils thick) which provides a cost-effective method of lining hazardous waste disposal facilities and preventing groundwater pollution. Poly-Flex is manufactured by Poly-America, one of the most modern extrusion facilities in the U.S., producing 150 million pounds of polyethylene per year. Poly-America's state-of-the-art quality control laboratory assures the finest quality polyethylene liner available.

Pressure Filtration Specialist

Incorporated

P.O. Box 686, 30 Mason St.

203/489-1221 or 485-2524 Torrington, CT 06790 Pressure Filtration Specialists, Incorporated (PFS)volume reduction of liquid waste. PFS's mobile, selfcontained, trailer-mounted filter presses reduce generator liquid sludge volume by producing filter cake of 35-60% solids by weight. This reduced volume offers substantial savings to generators on transportation and disposal costs. On-site sample testing available upon reauest.

Princeton Testing Laboratory

P.O. Box 3108 Princeton, NJ 08543

609/452-9050

Environmental analysis and industrial hygiene. Toxic waste/soil, RCRA, NJ ECRA, industrial wastewater NPDES, groundwater, OSHA workplace surveys, asbestos monitoring and evaluation, complete NIOSH lab methodology, stack testing, asbestos abatement training courses. Right-To-Know compliance, microbiology, AIHA accredited. NJ DEP Certified, NY DOH approved, PA DER approved.

OED Environmental Systems, Inc. P.O. Box 3726

Ann Arbor, MI 48106

Weli Wizard[®] dedicated groundwater sampling systems. Sample Pro® portable samplers and supplies, and Pulse PumpTM pneumatic pumping systems for leachate and contaminated water pumping are all featured in the OED Environmental Systems, Inc. line. Well Wizard dedicated bladder systems and purging aids are designed to meet the latest EPA sampling guidelines.

R.E. Wright Associates, Inc. 3240 Schoolhouse Rd

Middletown, PA 17057

R.E. Wright Associates, Inc. (REWAI) is an applied groundwater consulting firm providing professional services to conduct feasibility studies, site investigations, permitting and implementing of remedial measures. Capabilities include complete field testing, aquifer analysis, data collection, computer modeling and water and wastewater laboratory analysis. REWAI also designs and manufactures groundwater cleanup equipment, including the Auto-Skimmer, Air-Stripping Towers, Water Table Depression Pumps and Liquid Interface Samplers. The Auto-Skimmer automatically recovers subsurface spills of floating hydrocarbons from both large and small diameter wells.

Radian Corporation

P.O. Box 9948 Austin, TX 78766

512/454-4797 Technology-based company which provides professional services and specialty products to government and industry. Full range of services offered in environmental services, and specifically in the area of solid and hazardous waste management. These services include the areas of permitting; remedial action planning/implementation, soils, water, and waste analysis; and waste management facilities design.

Recra Environmental, Inc.

4248 Ridge Lea Rd.

Amherst, NY 14226

716/833-8203

313/995-2547

717/944-5501

Recra Environmental, Inc. is an independent firm supplying waste management services to the industrial and government communities in the form of professional consulting and laboratory testing. Chemical Control Management, waste minimization programs, site and plant assessments and PRP assistance coupled with environmental testing and waste characterizations encompass a portion of the services offered.

Resource Analysis, Inc. P.O. Box 4778 Hampton, NH 03842

603/927-7777

Resource Analysts and its affiliates provide comprehensive environmental testing service to industrial and commercial clients and to all levels of government. Specialties include organic chemistry using IR, GC and GC/MS analytical methods; inorganic and heavy metals chemistry; freshwater and marine aquatic toxicology; and field sampling. The laboratories occupy a 10,000 sq. ft. facility with a staff of 25 professionals.

Resource Technology Services

6 Berkeley Rd. Devon, PA 19333

215/687-4592

RTS is a hazardous waste management company offering expertise in the following areas: laboratory waste handling, laboratory services, drum and bulk waste and reactive and explosive waste removal and disposal. Remedial action and emergency response capabilities are also offered.

Resources Conservation Company 3101 NE Northup Way Bellevue, WA 98004

Resources Conservation Co. is an environmental systems engineering firm specializing in resource recovery and environmental reclamation. RCC provides complete services including laboratory testing, process development, design engineering and turnkey construction. RCC's 15 years of experience has led to the development of several patented processes such as B.E.S.T. for hazardous sludge processing; the Brine Concentrator for water recovery and waste reduction. Dow Chemical's AquaDetox is also available for air/ stream stripping of volatile pollutants from wastewater.

Rexmord-Envirex/EETC 5103 W. Beloit Rd.

Milwaukee, WI 53214

414/643-2668

Remord Breathing Systems offers the Biopak 60, onehour SCBA and the Biopak 240 four-hour SCBA. The units are positive-pressure, light, compact, and easy to use and maintain. Rexnord, through its wholly owned subsidiary. Envirex, offers a broad range of services-analytical lab, bench treatability, pilot plant tests and scaled-up, installed systems. Processes include chemical treatment, solids separation and dewatering, filtration, aeration, air stripping, adsorption and desalting, if needed. Site-specific combinations of costeffective physchem/biological systems are offered. Biological systems can be aerobic or anaerobic. Multiprocess mobile systems are also available. Envirex's Bio-Nomics Division offers mobile dewatering systems.

Riedei Environmental Services. Inc.

P.O. Box 5007 Portland, OR 97208-3320

503/286-4656

RES provides diverse environmental services including environmental consulting and engineering, groundwater, remedial action and studies, hazardous waste management, emergency response for oil or hazardous waste spills or releases. Engineers, designs, installs and operates petroleum hydrocarbon recovery systems. Provides services for industry and government from regional offices in St. Louis, MO; Portland, OR; Richmond and Los Angeles, CA.

Roy F. Weston, Inc. Weston Way

West Chester PA 19380

215/692-3030

Managers of major environmental projects including facilities design, construction, operation, remedial actions, permitting, closures, investigations and analytical chemical analyses.

S.R.Analytical Inc.

28 Springdale Rd. Cherry Hill, NJ 08003

609/751-1122

S-R Analytical is a full service environmental laboratory specializing in the analysis of environmental samples; priority pollutant and HSL compounds, RCRA classification, hazardous waste characterization, and offers a full range of field sampling and testing services.

SAIC

8400 Westpark Dr. McLean, VA 22102

701/821-4749

SAIC is an employee-owned company principally involved in the application of scientific expertise to solve complex technical problems. SAIC offers a full range of environmental consulting services including hazardous waste site investigations and feasibility studies, wastewater engineering, analytical chemistry, groundwater modeling, risk assessments, regulatory compliance and specialized laboratory studies.

SCS Engineers

11260 Roger Bacon Dr. Reston, VA 22090

703/471-6150

Specialists in solid and hazardous waste management since 1970, Services include remedial investigations, feasibility studies, remedial action design and construction supervision. The firm provides permitting assistance and prepares closure plans. SCS is one of a few national firms offering subsurface gas migration control design and construction services. Offices nationwide.

206/828-2225

SMC Martin Inc. 900 W. Valley Forge Rd. P.O. Box 859 Valley Forge, PA 19482

215/265-2700

SMC Martin Inc. provides engineering and geotechnical services to industry and government including remedial investigations and feasibility studies for hazardous and solid waste disposal sites; wastewater treatment; environmental assessment; legal advisory services; permit application assistance; environmental monitoring; construction management; closure plan design; and engineering/financial analyses.

SRE Analytics, Inc. 2910 Turnpike Dr. Hatboro, PA 19040

215/674-1202

A full service testing laboratory serving the waste management industry. Broad spectrum of analytical capabilities ranging from drinking water analyses to organic/priority pollutant analyses. State-of-the-art instrumentation includes GC/MS, GC, ICP, TOC and TOX. Other services include contract research & development and consulting.

Sevenson Containment Corporation 2749 Lockport Rd.

Niagara Falls, NY 14302

716/284-0431

Sevenson Containment Corporation provides turnkey services to government and industry in the areas of hazardous waste management and waste site cleanup. Sevenson's full service capabilities include: site restoration; secure landfill construction; slurry wall & trench construction; sludge solidification & fixation; waste recovery and treatment; drum removal and waste excavation, transportation and disposal.

Shirco Infrared Systems, 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 material 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 is available for on-site testing at your facility.

Silidur North American Company

P.O. Box 1043 Elyria, OH 44036

216/277-0981

An imbankment stabilization process for stable and unstable soil conditions. It addresses all types of slips and channel work very cost-effectively. It functions as a flexible concrete retaining wall that turns into a living wall.

Skolnik Industries, Inc.

4601 W. 48th St. Chicago, IL 60632-4896

312/735-0700

Manufacturer of Hazardous Material Containers from 8 to 85 US Gallon Capacities including "Big Mouth," the 85 Gallon Salvage Drum and "Quad-Pak," the assortment of 4 nested containers. Also, the SECURITY Drum accessories.

Soil & Material Engineers, Inc.

P.O. Box 609

Cary, NC 27511

919/481-0397

Soil & Material Engineers provides a comprehensive range of environmental and geotechnical engineering services to help you solve your hazardous substance problems. We will interpret your responsibilities under the regulations, investigate your hazardous substance problems, and provide you with a cost-effective solution. We are ready to serve you-call us!

Solinst Canada Ltd.

2440 Industrial St.

416/335-5611 Burlington, Ont., Canada L7P 1A5 Solinst manufactures high quality groundwater instrumentation. Solinst Water Level Meters offer fast, accurate measurements using a ridged flat tape with stainless steel conductors and permanent markings every 0.05 ft. The equipment ranges to include the Waterloo Multilevel System for obtaining samples from many different levels in a single borehole in bedrock.

Southwest Research Institute

6220 Culebra Rd. San Antonio, TX 78284

512/684-5111 Description of projects involving leak detection and liquid waste impoundment (scale model demonstration of electrical method for locating leaks in plastic liners). Description of failure mode testing of geomembrane materials.

Sybron Chemicals Inc.

Birmingham Rd., P.O. Box 66 Birmingham, NJ 08011

609/893-1100

212/296-4371

Leaders in the application of Augmented Bioreclamation (ABR) for the treatment of contaminated soil and groundwater. Capabilities include biosystems engineering services and supply of selectively adapted organisms for specific contaminants. Technology useful for cleanup of chemicals from leaking storage tanks, pipeline spills, train derailments, etc. Advantages are ultimate disposal technology and low cost.

TAMS Engineering

655 Third Ave. New York, NY 10017

TAMS, a leading international engineering firm, offers comprehensive services in solid and hazardous waste management. Capabilities include RI/FS; QA/QC; Health/Safety; Risk Assessment; Community Relations; Remedial Design; Construction Supervision; Site Closure; Waste Geotechnics; Chemical/Process Design; Watershed Management; Hydrogeology/Mathematical Modeling. TAMS provides services to clients in government, military and private sectors through offices in maior cities.

TRC Environmental Consultants, Inc.

800 Connecticut Blvd.	
East Hartford, CT 06108	203/289-8631
Environmental Consulting Services.	

Target Environmental Services, Inc.

5513 Twin Knolls Rd., Suite 216 Columbia, MD 21045

Target Environmental is a leader in the development and use of Soil Gas sampling and analytical techniques for the detection of subsurface contamination. A highly experienced staff and an EPA-approved laboratory furnish the technical quality required for a cost-effective

and accurate evaluation of the extent, composition and

concentration of soil and groundwater contamination.

Technos, Inc.

3333 NW 21st St. Miami, FL 33142

305/634-4507

818-449-6400

301/992-6622

Technos specializes in contaminant hydrology, groundwater and geologic hazards site investigations, and leads the industry in the high resolution surface and downhole geophysics, statistical geomorphology, complex and fracture flow analysis, in situ contaminant and flow measurements, and advanced groundwater modeling, computer graphics and data processing.

Tetra Tech, Inc.

(A Honeywell Subsidiary) 630 N. Rosemead Blvd. Pasadena, CA 91107

Tetra Tech provides water resource and hazardous material management services for industrial, institutional and governmental clients throughout the U.S. The firm's hazardous waste management services include: materials management, waste characterization, emergency response, risk assessment, feasibility studies, geohydrologic investigations, SPCC/contingency plans, health and safety training.

Thermo Electron Instruments Inc. (AID) 108 South St

Hopkinton, MA 01748

617/432-5321

Manufacturer of instruments both portable and stationary to measure organic toxic chemicals and air. water and soil pollutants. Also manufactures ambient and stack monitoring systems. Will feature Portable Gas Chromatographs, Organic Vapor Analyzers and Total Hydrocarbon Analyzers.

Tigg Corp.

P.O. Box 11661 Pittsburgh, PA 15228

412/563-4300

Manufacturers of Modular Adsorbers designed for the remediation of vapor and water pollution. The combination of over 30 years of experience with adsorbents and systems provides unique capabilities of technical expertise and product availability to address specific remedial problems with the most appropriate technology.

Toxic Treatment (USA) Inc.

901 Mariner's Island Blvd., Suite 315

415/572-2994 San Mateo, CA 94404

Toxic Treatment USA, Inc., (TTUSA), is a subsidiary of Toxic Treatments Limited (TTL), an Australianbased public company. TTL owns the technologies developed by Alternative Technologies for Waste, Inc. (ATW), and the In-Situ Detoxifier prototype built by Calwed Inc. The equipment has been successfully field tested removing concentrated hydrocarbons from contaminated soil. TTUSA is further developing and marketing the In-Situ Detoxifier System.

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 U.S. EPA 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 architectengineer firms and construction contractors take advantage of work available to them through the Corps of Engineers.

U.S. Army Environmental Hygiene Agency Aberdeen Proving Ground Aberdeen, MD 21010

301/671-2024

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 401 M St., SW Washington, DC 20460

202/382-5100

The Superfund law provides the authority to respond to problems at uncontrolled hazardous waste sites in emergency situations and at sites where long-term permanent remedies are required. The Emergency Response Team responds to releases which pose an immediate threat to the public health and environment and provides R&D assistance in providing long-term remedies. The long-term remedies are performed by states, the U.S. EPA via the Army Corps of Engineers, or responsible parties.

U.S. Geological Survey

790 National Center Reston, VA 22092 703/648-4377 Panels depicting research and products of the U.S. Geological Survey dealing with earth sciences.

US Ecology, Inc.

P.O. Box 7236 Louisville, KY 40207 800/626-5317

US Ecology, Inc., a subsidiary of American Ecology, is a full-service waste management firm. The company operates hazardous waste disposal facilities near Robstown, TX and Beatty, NV. Both facilities accept RCRA hazardous solid waste, and the Beatty facility also disposes of PCB waste and low-level radioactive waste (LLRW). In addition, US Ecology provides cleanup services for hazardous waste.

VFL Technology Corporation

42 Lloyd Ave.

Malvern, PA 19355

215/296-2233

VFL Technology offers solidification and stabilization services for organic and non-organic liquids, sludges and soils. In situ stabilization provides permanent chemical encapsulation at a fraction of off-site disposal costs. Our field construction groups have developed and implemented cost-effective on-site closures for impoundments ranging from 2 - 200 thousand cubic yards.

WAPORA, Inc.

1555 Wilson Blvd., Suite 700 Rosslyn, VA 22209 703/524-1171

WAPORA, a minority business enterprise, offers over 17 years of experience in the conduct of environmental investigations. WAPORA specializes in hazardous wastes site investigations, remedial action planning, regulatory negotiations and cleanup supervision. Our offices are located in Washington, DC, Atlanta, Dallas, Cincinnati and New Jersey.

Wadsworth/ALERT Laboratories, Inc. 1600 Fourth St., SE Canton, OH 44707 216/454-5809

Since 1938, Wadsworth/ALERT Laboratories, Inc. has offered independent laboratory analytical services-meeting the needs of industry, government and private concerns. WAL is a U.S. EPA Contract Laboratory in the Superfund program, actively participates with mobile lab services in ERCS Zones I, II and III and maintains drinking water certifications throughout the U.S. WAL has available 6 GC/MS systems, multiple GC units, industrial hygiene testing and a complete wet chemistry lab. Programs include 'Appendix IX,' TCLP, RCRA, TSCA, SDWA, NPDES and others. Rush services available. Waste Conversions, Inc. 2951C Advance Ln. Colmar, PA 18915

215/822-2676

Waste Conversions, Inc. is a full-service environmental management company offering services including consulting, analysis, quality control, liquid treatment, solidification, solids processing, oil recycling, drum handling, lab packing, transportation, manifest expertise, secure landfill, emergency response, on-site dewatering, site evaluation, site cleanup, ECRA services, regulatory liaison and tank cleaning.

Waste Documentation and Control, Inc.

P.O. Box 7363 Beaumont, TX 77706

409/839-4495

604/984 4715

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.

Waste-Tech Services, Inc.

18400 W. 10th Ave.

Golden, CO 80401 303/279-9712 We offer on-site combustion services using a fluidized bed combustor that destroys both hazardous and toxic wastes in solid, liquid, slurry and gaseous form. We offer a worry-free service because we own, operate, permit, maintain and service the transportable fluid bed combustor.

Westbay Instruments Ltd.

507 E. Third St. N. Vancouver, B.C. Canada V7L-1G4

Westbay Instruments Ltd.—designers and manufacturers of the MP system, a modular multiple level 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. Wilson Laboratories 525 N. 8th, P.O. Box 1884 Salina, KS 67401

913/825-7186

Full service analytical laboratory specializing in environmental monitoring and the analysis of hazardous waste samples. Expertise includes GC/MS, GC, HPLC and industrial hygiene. Participant in TCLP, zero headspace extraction method validation study.

Woodward-Clyde Consultants

 201 Willowbrook Blvd.

 Wayne, NJ 07470
 201/785-0700 x450

 Consulting Engineers, Geologists and Environmental Scientists.

 YWC, Inc.

 200 Monroe Tnpk.

 Monroe, CT 06468
 203/261-4458

A multidisciplinary environmental laboratory/engineering consulting firm, YWC, Inc. provides air, soil, water and waste characterization for full-profile site assessments. The York Laboratories Division is a participant in EPA's Contract Laboratory Program. Additional services available include contract operation of wastewater treatment facilities, interim sludge dewatering services, hazardous waste management and remedial investigation/feasibility studies. Growth has been achieved through dedicated personal service with an emphasis on quality at most competitive prices.

Yellow Springs Instrument Co., Inc.

P.O. Box 279 Yellow Springs, OH 45387

513/767-7241

YSI manufactures a complete line of products for precise, reliable measurement of conductivity, dissolved oxygen and temperature using EPA, APHA and ASTM apoproved methodology. YSI recently introduced the Model 3000 T-L-C, a portable, self-contained instrument for monitoring Temperature-Level-Conductivity of groundwater or surface water.

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