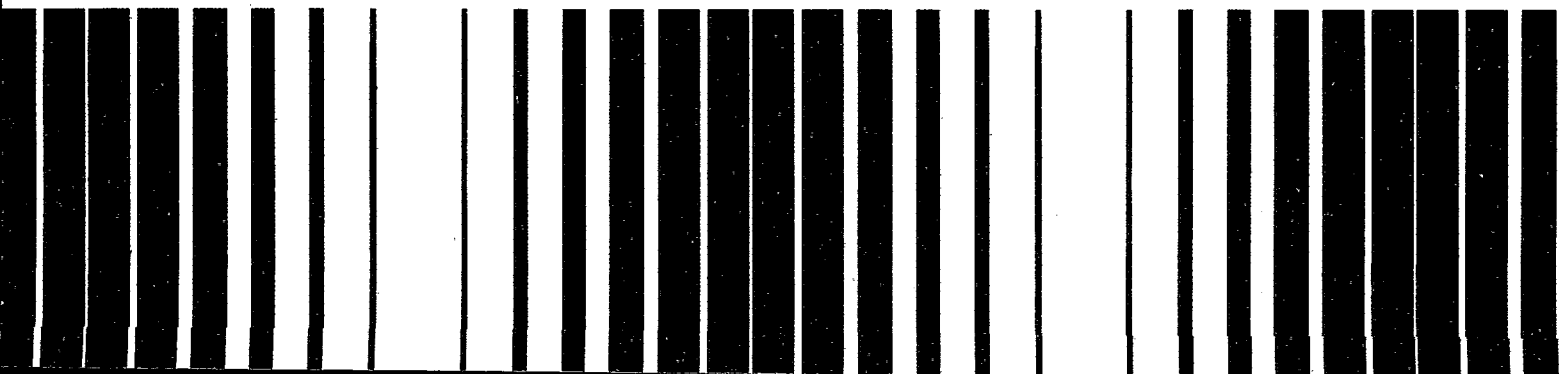
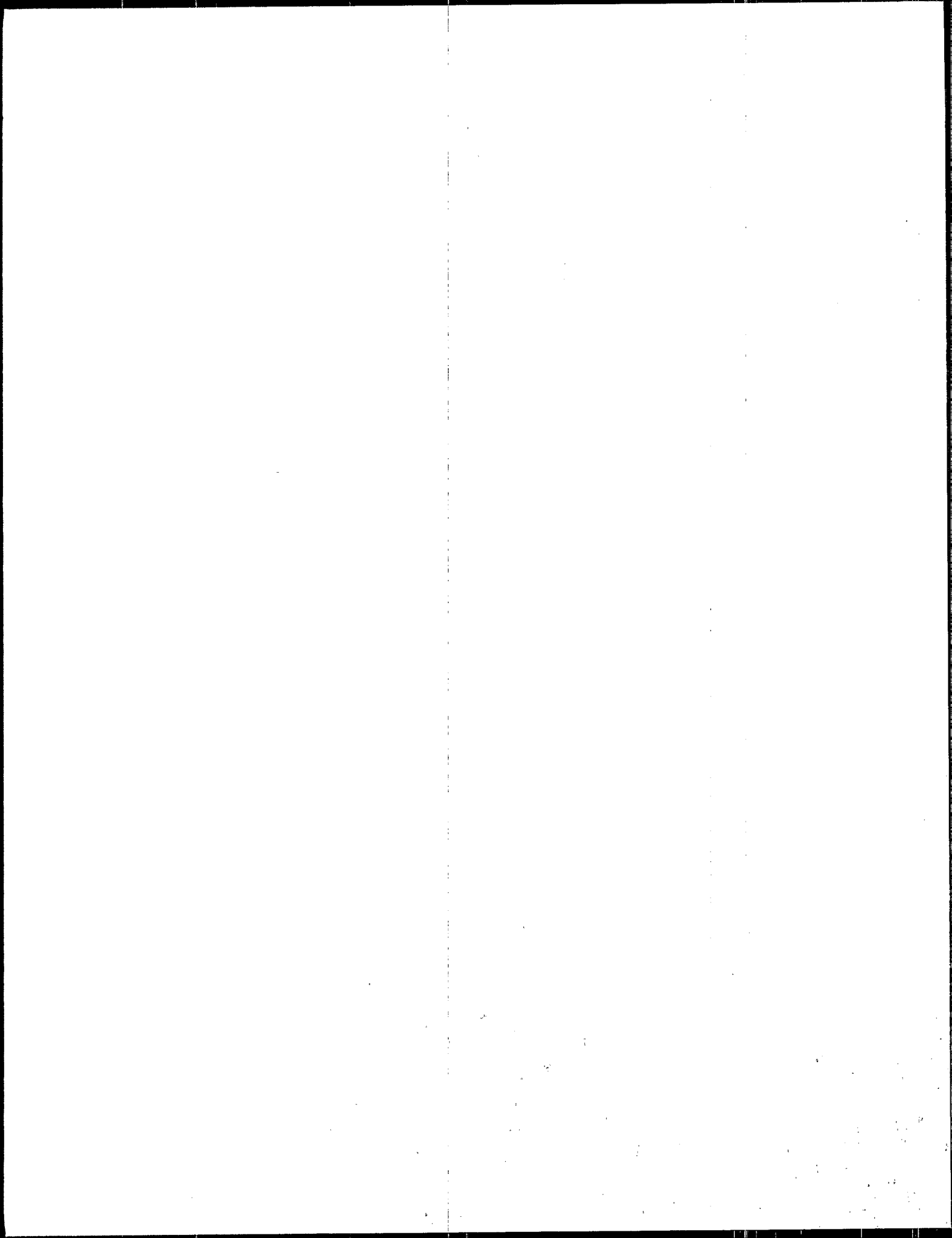




Seminar Publication

Corrective Action: Technologies and Applications





Seminar Publication

Corrective Action:

Technologies and Applications

U.S. Environmental Protection Agency
Cincinnati, OH 45268



Printed on Recycled Paper

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This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Preface

This seminar publication is wholly based on edited versions of presentations made at U.S. Environmental Protection Agency (EPA) Technology Transfer Seminars entitled "Corrective Actions: Technologies and Applications". These seminars were held in Houston, Texas (March 30-31, 1988); Atlanta, Georgia (April 19-20, 1988); Chicago, Illinois (May 25-26, 1988); Philadelphia, Pennsylvania (June 7-8, 1988); and Los Angeles, California (June 14-15, 1988).

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This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. The process alternatives, trade names, and commercial products are presented as examples and are not endorsed or recommended by the EPA. Other alternatives may exist and may be developed. In addition, the information in this document does not necessarily reflect the policy of the EPA, and no official endorsement should be inferred.

Abstract

The Corrective Action Program is currently under development by the RCRA Enforcement Division in the Office of Waste Programs Enforcement. To provide engineers and scientists involved in RCRA Corrective Action activities, from a industrial perspective, with insight into the selection and evaluation of technologies suitable for application in the containment and treatment of hazardous releases.

Five seminars were held in the spring and summer of 1988 in Houston, Texas; Chicago, Illinois; Atlanta, Georgia; Philadelphia, Pennsylvania; and Los Angeles, California. Support for the seminars came from the RCRA Enforcement Division of the Office of Waste Program Enforcement. This publication contains edited versions of what was presented at each of the five seminars.

The seminar publication provides information on the identification, selection and application of technologies suitable for controlling and treating releases of hazardous wastes or their constituents from RCRA treatment, storage and disposal facilities. Applications of technologies are presented, where appropriate, to demonstrate the suitability of treatment options for specific waste types. In addition, factors to consider when implementing corrective measures at operating facilities are reviewed. Whenever possible, information has been updated and revised to take into account recent changes in the regulations.

This publication is not a design manual, nor does it include all the technologies available for corrective action. Additional sources should be consulted for more detailed information and design criteria. State and local authorities should be contacted for regulations as needed in local areas.

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List of Acronyms

APC	Air Pollution Control
APC	Dir Pollution Control Device
BOD	Biochemical Oxygen Demand
CAP	Corrective Action Plan
CFR	Code of Federal Regulations
CM	Corrective Measures
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COD	Chemical Oxygen Demand
DRE	Destruction Removal Efficiency
EM	Electromagnetic Conductivity
EP Tox	Extraction Procedure Toxicity Test
EPA	Environmental Protection Agency
FML	Flexible Membrane Liner
GC	Gas Chromatograph
GC/MS	Gas Chromatograph/Mass Spectrophotometer
gpm	gallons per minute
GPR	Ground Penetrating Radar
HHE	Human Health and the Environment
HWF	Hazardous Waste Fuel
kw	kilowatt
lb/hr	pound per hour
MAG	Magnetometry
MD	Metal Detection
MEK	Methyl Ethyl Ketone
mg/l	milligrams per liter
MMBtu/hr	million Btu per hour
ORP	Oxidation Reduction Potential
PAC	Powdered Activated Carbon
PCB	Polychlorinated Biphenyl

List of Acronyms (Continued)

PCP	Pentachlorophenol
PID	Photoionization Detector
ppb	parts per billion
ppm	parts per million
PVC	Polyvinyl Chloride
RBC	Rotating Biological Contactor
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
SBR	Sequencing Batch Reactor
SITE Program	Superfund Innovative Technology Evaluation Program
TCDD	Trichlorodibenzodioxin
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total Organic Carbon
tph	tons per hour
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
UV	Ultraviolet
VOC	Volatile Organic Compounds
µg/l	micrograms per liter

Chapter 1

Engineering Overview of the Corrective Action Program

The technical differences between site problems at RCRA facilities and CERCLA sites sometimes may be difficult to distinguish, owing to similarities in present or past uses of the site, in hydrogeologic setting, and/or in the types of substances disposed, spilled, or otherwise managed at the site. Consequently, many technical aspects of the study and remediation of releases of hazardous wastes and constituents from RCRA facilities often will closely parallel those at Superfund sites, and cleanups under both statutes must achieve similar goals for protection of public health and the environment. Additionally, activities which would be termed removal actions or expedited response actions under CERCLA may be undertaken by owners and operators under RCRA. In the RCRA context, such actions are termed interim measures, as will be discussed in subsequent chapters.

Differences between the two programs may arise in several areas: (1) who performs the work, (2) extent of the analyses and/or cleanup performed, (3) factors considered in selecting a final remedy, and (4) use of the site following cleanup. First, a Superfund cleanup may be undertaken by EPA under CERCLA Section 104, or by the responsible parties under EPA or state supervision under CERCLA Section 106. Corrective actions at RCRA facilities, on the other hand, are developed and implemented by the owner/operator under EPA or state supervision, either through the facility permit or an enforcement order. Second, at some RCRA facilities the Corrective Action process may be somewhat more streamlined than at a CERCLA site. This could occur in situations where much is already known about the wastes and the site at the initiation of Corrective Actions from the Part B permit application and other submittals; and, where the release problem is relatively minor or the remedial alternatives to address it are relatively minor or the remedial alternatives to address it are relatively straightforward or self-evident. Third, while the remedy selection factors in the draft RCRA Corrective Action regulations (40 CFR 264 Subpart S) are expected generally to parallel those offered in the proposed revisions to Superfund's National Contingency Plan, cost and cost-effectiveness may not be used as a basis for selecting remedies under the RCRA statute. Finally, in many cases Corrective

Actions at a RCRA facility may culminate in its return to normal operating status; while at most Superfund sites (and at some RCRA facilities undergoing Corrective Action), these activities typically culminate in final cleanup or closure of the site. These and other factors might lead to selection and implementation of different corrective measures at otherwise similar RCRA and Superfund sites.

As of this writing, the proposed Subpart S regulations describing many procedural aspects of the RCRA Corrective Action program have not been published. However, two documents provide the framework for directing the development of the site-specific work to be performed by the owner/operator in the facility's Corrective Action program: the *RCRA Corrective Action Plan - Interim Final* (U.S. EPA, 1988a) and *RCRA Corrective Action Interim Measures - Interim Final* (U.S. EPA, 1988b). These can be used to develop site-specific schedules of compliance for incorporation into a permit or an enforcement order. From an engineering perspective, these documents provide scopes of work that can assist owner/operators and engineers in planning each phase of a facility-wide Corrective Action program, and in the formulation and implementation of interim measures, respectively. Additional guidance currently is under development.

What Triggers Corrective Action

A common question is "What triggers Corrective Action?" There is no single answer. In general, any indicator that a release of hazardous wastes is occurring (or has occurred) can serve as a trigger. Thus, a fish kill, a reported spill, contaminated drinking water or contamination in monitoring wells are some examples of conditions that may result in the EPA's initiating a Corrective Action program. An initial step may be a RCRA Facility Assessment (RFA), which is conducted by the EPA and intended to identify releases or potential releases of hazardous wastes and/or constituents. Usually the RFA is completed before the Corrective Action process is initiated. If releases or potential releases are found that may threaten public health and the environment, the Agency may require the owner

and/or operator to develop a Corrective Action Plan to address the releases.

The Corrective Action Plan

The Corrective Action Plan (CAP) relies on the sequential performance of activities which are conventional engineering practices. These activities include problem identification, development and evaluation of alternatives, and the implementation of the selected alternative. The three analogous phases identified in the CAP are as follows:

- RCRA Facility Investigation (RFI) - site characterization and pre-investigation identification of possible containment/treatment technologies;
- Corrective Measures Study (CMS) - the conduct of detailed feasibility studies of the cleanup alternatives identified;
- Corrective Measures Implementation (CMI) - those activities associated with the design and construction of the technology options selected and with performance monitoring.

The CAP can serve as the technical framework for a Corrective Action program. The CAP provides a "menu" of activities or information requirements that may be necessary for each phase of the process. Site-specific conditions and the nature and extent of the contamination will determine which tasks will be necessary. The necessary tasks will be enforceable through permit conditions or by an administrative order or judicial action. The CAP can serve as a flexible engineering guide for the regulatory community in implementing their own Corrective Action Program.

Interim Measures

At this writing, the Interim Final guidance for the regulatory community with regard to interim measures is available (U.S. EPA, 1988). Based on this guidance, the general concepts for the application of interim measures can be identified.

Where there is an imminent threat to human health and the environment, as well as in some non-emergency situations, the regulatory agency may ascertain that a response is appropriate prior to the completion of the RCRA Facility Investigation or the Corrective Measures Study. Hence, the decision for interim measures can be made based on the immediacy as well as the magnitude of the potential threat to human health or the environment; the nature of appropriate Corrective Action; the implications of deferring Corrective Action until the RCRA Facility Investigation and Corrective Measure Study is complete; and other factors.

Once a decision is made that interim measures are needed, then the next question is what interim measures might be required for this particular situation. Examples of interim measures for various RCRA treatment, storage and disposal facilities, and for various release types are listed in Table 1. Note that these are examples; their inclusion does not infer either guidance or approval.

Interim measures may be separate from the comprehensive Corrective Action plan but should be consistent with, and integrated with, any longer-term Corrective Action (e.g., corrective measure through an order, an operating permit, a post-closure permit or interim status closure requirements). To the extent possible, interim measures should not seriously complicate the ultimate physical management of hazardous wastes or constituents; nor should they present or exacerbate a health or environmental threat. Interim measures may add additional costs or work to the comprehensive Corrective Action. Such added costs or work do not preclude implementation of an interim measure.

Table 1. Examples of Interim Measures

The following is a list of possible interim measures for various units and release types. This list is not considered to be all-inclusive. More information is available through the *Interim Measures Guidance - Interim Final* (U.S. EPA, 1988b).

Containers	
1.	Overpack/Redrum
2.	Construct Storage Area; Move to New Storage Area
3.	Segregation
4.	Sampling and Analysis
5.	Treatment, Storage and/or Disposal
6.	Temporary Cover
Tanks	
1.	Overflow; Secondary Containment
2.	Leak Detection/Repair; Partial or Complete Removal
Surface Impoundments	
1.	Reduce Head
2.	Remove Free Liquids and Highly Mobile Wastes
3.	Stabilize/Repair Side Walls, Dikes or Liner(s)
4.	Temporary Cover
5.	Run-off/Run-on Control (Diversion or Collection Devices)
6.	Sample and Analyze to Document the Concentration of Constituents Left in Place When a Surface Impoundment Handling Characteristic Wastes is Clean Closed
7.	Interim Groundwater Measures (See Groundwater Section of this table)
Landfills	
1.	Run-off/Run-on Control (Diversion or Collection Devices)
2.	Reduce Head on Liner and/or in Leachate Collection System
3.	Inspect Leachate Collection/Removal System or French Drain
4.	Repair Leachate Collection/Removal System or French Drain
5.	Temporary Cap
6.	Waste Removal (See Soils Section of this table)
7.	Interim Groundwater Measures (See Groundwater Section of this table)
Waste Piles	
1.	Run-off/Run-on Control (Diversion or Collection Devices)
2.	Temporary Cover
3.	Waste Removal (See Soils Section of this table)
4.	Interim Groundwater Measures (See Groundwater Section of this table)
Soils	
1.	Sampling/Analysis; Disposal
2.	Run-off/Run-on Control (Diversion or Collection Devices)
3.	Temporary Cap/Cover
Groundwater	
1.	Delineation/Verification of Gross Contamination
2.	Sampling and Analysis
3.	Interceptor Trench/Sump/Subsurface Drain
4.	Pump and Treat; In-situ Treatment
5.	Temporary Cap/Cover
Surface Water Releases (Point and Non-point)	
1.	Overflow/Underflow Dams
2.	Filter Fences
3.	Run-off/Run-on Control (Diversion or Collection Devices)
4.	Regrading/Revegetation
5.	Sample and Analyze Surface Waters and Sediments or Point Source Discharges

Table 1. (Continued)

Gas Migration Control	
1.	Barriers/Collection/Treatment/Monitoring
Particulate Emissions	
1.	Truck Wash (Decontamination Unit)
2.	Revegetation
3.	Application of Dust Suppressant
Other Actions	
1.	Fencing to Prevent Direct Contact
2.	Sampling Off-site Areas
3.	Alternate Water Supply to Replace Contaminated Drinking Water
4.	Temporary Relocation of Exposed Population*
5.	Temporary or Permanent Injunction*
6.	Suspend or Revoke Authorization to Operate Under Interim Status*

*Model language not included in *Interim Measures Guidance - Interim Final*.

References

U.S. EPA. 1988a. RCRA Corrective Action Plan - Interim Final EPA/530-SW-88-028, OSWER 9902.3, Office of Solid Waste and Emergency Response, Washington, D.C., June 1988.

U.S. EPA. 1988b. RCRA Corrective Action Interim Measures Guidance - Interim Final EPA/530-SW-88-029, OSWER 9902.4, Office of Solid Waste and Emergency Response, Washington, D.C., June 1988.

Chapter 2

Engineering Considerations in the Facility Investigation

If the RFA or other information has indicated a release of hazardous constituents, then from the owner/operator's perspective, the Corrective Action process truly begins. The first step in the process, the RCRA Facility Investigation (RFI), is directed toward development of the engineering information about the site necessary to permit selection and evaluation of remedial alternatives. The main engineering thrust of the RFI is the characterization of site conditions by defining the nature and extent of the problem.

The data collection efforts for site characterization may be expensive and time consuming. Certain additional data will be needed to evaluate potential Corrective Action options. Therefore, it is postulated that if a preliminary screening of possible Corrective Action options is made before data collection for site characterization begins, the data necessary to evaluate candidate Corrective Action options can be collected concurrently with the site characterization data. For example, the nature of the identified release, as well as the owner/operator's knowledge of hazardous materials used in the past, can give some indication of the media contaminated and the possible type(s) of contamination. Such information gives the engineer guidance in identifying potential Corrective Action technologies. Furthermore, because the time normally required to conduct the RFI can be as long as 24 months; lab, bench and pilot tests can be conducted to confirm the applicability of candidate technologies and to develop system design information, if deemed appropriate.

Design of the RFI should incorporate the following considerations:

- Both containment and treatment may be options;
- Different options may be selected to address different units;
- At any given unit/area, a combination of technologies (e.g., treatment train) may be needed to fully address the problem.

Identification of what contaminants are in what media is only part of the objectives of the RFI. In

addition, treatability information is required which addresses the physical/chemical properties of the contaminated media.

From an engineering standpoint, the initial step in the RFI would be to collect historical information about past practices to provide insight into the possible source(s) of the release, the type and quantities of releases, and potential pollutant migration pathways. The next step would be to identify possible technologies which may be needed to halt the migration of the pollutant and to remove and/or treat the contaminants in the various media (i.e., soil, groundwater, etc.) in which the contaminants are found. Through identification of what is known about the site and what possible Corrective Action and/or containment scenarios might be needed for cleanup, a plan can be developed to fill the data gaps during the RFI. This chapter is directed toward the following RFI engineering activities:

- Pre-investigation identification of candidate treatment options for containing and/or treating contaminants;
- Field diagnostic tools which can be used to characterize the site;
- Bench- and pilot-scale study considerations.

Pre-Investigation Evaluation of Corrective Measures Technologies

During the RFI stage of a Corrective Action program, only limited information about the site and waste may be available. Some historical data about the facility and its past practices and operating conditions may be developed from plant records. In addition, the RFA may provide some information about the contaminants and contaminated media. Because such information is limited, only general classes of treatment technologies can be identified initially (e.g., the material is organic, so thermal processes might work). Such identification of general treatment options is helpful in planning, since the data collection for site characterization and

treatment selection can be dealt with simultaneously. This approach makes the field sampling program more cost effective and efficient.

Strategy for Containment Selection:

Early in the Corrective Action process, a decision may be made concerning whether or not containment is necessary to protect human health and the environment (HHE). If the release or threatened release presents danger to HHE, immediate action must be taken to halt migration. Under these circumstances, actions termed "Interim Measures" may be required, and excavation or containment measures may be directed by the regulatory agency. However, the Owner/Operator will be responsible for their implementation. In the event that containment is not required as an interim measure, containment may still be needed as part of the overall Corrective Action to halt the pollution migration if wastes or contaminants are to be left on-site.

Based on the existent site information, the questions which need to be answered to determine if containment is needed are:

- In what medium is the contamination located?
- What is the source of contamination?
- What are pollutant migration pathways?
- What are the potential receptors?
- Can the contamination be contained?

Once the medium and a general understanding of the chemical composition of the waste or contaminant is known, a number of containment alternatives can be identified. Table 2 presents the general classes of containment technologies for various contaminated media along with data needs for technology evaluation. Table 3 presents a summary of important geological information required as part of the data to be collected to support selection of containment technologies.

Strategy For Treatment Selection

The purpose of treatment is to alter the function, form or quantity of the waste, or media contaminated by the releases, by changing its mobility, its volume, or its toxicity. The hierarchy of hazardous waste management establishes that a change (reduction) in toxicity is the main treatment objective. The next level of acceptable objectives is providing a change (reduction) in mobility. The least desirable strategy, other than storage, is producing a change in volume, unless producing that change will facilitate treatment by another means. The general options for treatment based on these alterations are shown in Figure 1.

If the primary intent is to detoxify the waste, then the characteristics of the waste which make the waste

hazardous (and whether the contaminant is organic or inorganic) become issues. Accordingly, the questions then become the following:

- Is it toxic?
- Is it reactive?
- Is it corrosive?
- Is it ignitable?

Table 4 allows a generic identification of the various technology options suitable for treating wastes based on their hazardous characteristics and physical form. Table 4 also identifies the kinds of data which must be collected to perform a valid evaluation of those technologies. The physical treatment data needs for different media shown in Table 5 are typically required in addition to those presented in Table 4.

Field Diagnostic Tools

There are many field diagnostic tools available for characterization of a contaminated site. In the preliminary site investigation, screening techniques can be used to locate areas of contamination by non-invasive methods. Then in the detailed site investigation, sampling and monitoring techniques which provide greater quantification of contaminants can be focused on those areas identified. As would be expected, screening techniques are typically rapid and qualitative as well as being less expensive than detailed sampling and monitoring techniques.

Preliminary site investigation (screening) techniques typically include geophysical surveys, soil gas monitoring, surface water sampling, and limited groundwater sampling. Of these, geophysical techniques (which measure some physical property of the soil or contaminant) are useful for locating buried wastes, contaminated soils and groundwater. Screening techniques would not usually incorporate the drilling of wells for core analysis or groundwater sampling.

Detailed sampling can include, but is not limited to, the installation of monitoring well networks. After the wells have been installed, aquifer tests are typically performed. Once the aquifer tests are performed and the aquifer characteristics are determined, time series sampling for a given contaminant, or a surrogate, is undertaken. The combined results of these efforts provide the basis for development of a treatment strategy. Modeling can be used as part of this effort to help determine the best technical and most cost-effective techniques to be used at a site.

Geophysical Techniques

Geophysical techniques can be used for many purposes, such as to: (1) map hidden hydrogeologic features, (2) map leachate plumes and zones of

Figure 1 Alteration of function and data needs.

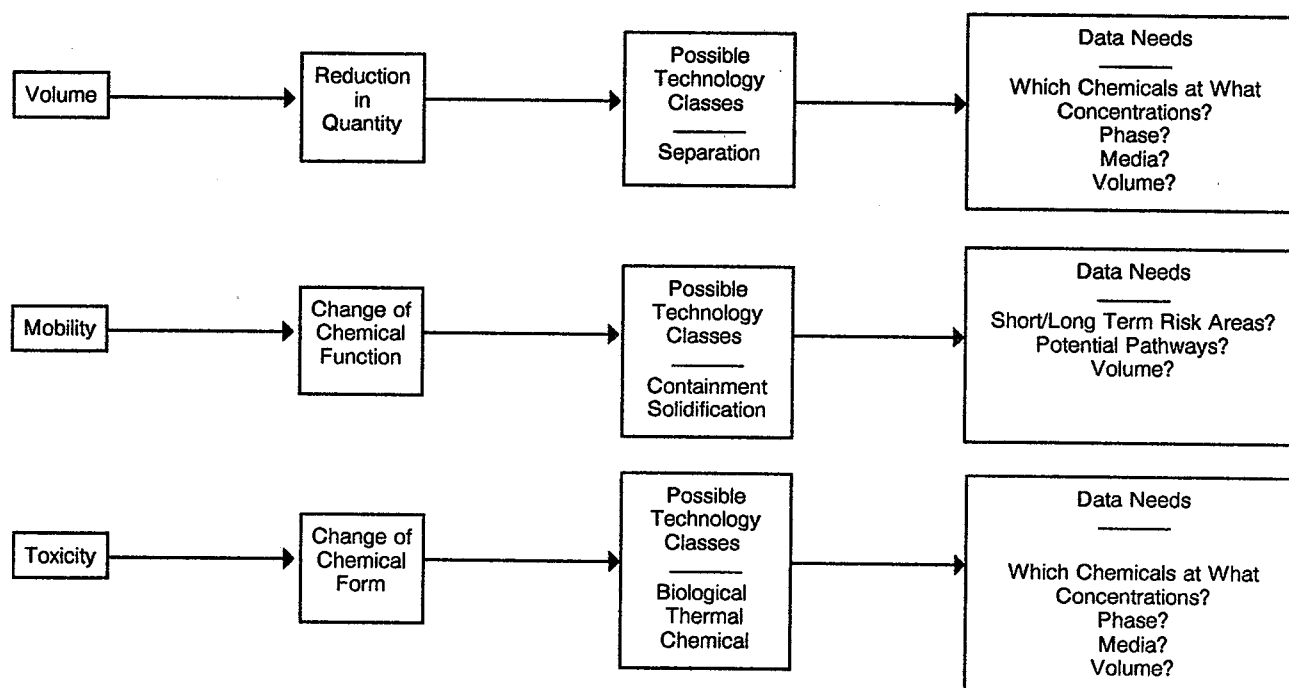


Table 2. Containment/Recovery Options and Data Needs by Media

	Soils	Groundwater	Surface Water/Sediments	Air
Principal Option for Containment/Recovery	Excavation Vacuum extraction Temporary cap/cover Hydraulic modification No action	Groundwater pumping Subsurface drains Hydraulic barriers Low permeability barriers No action	Overflow/underflow containment (i.e. oil booms) Run off/run on control Diversion/collection No action	Capping/insulation Operations modifications Gas collection/removal No action
Data needed	Soil stratigraphy Soil hydrology Surface topography Engineered features Chemical composition of contacted soil	Subsurface soil conditions Aquifer properties Geochemical environment Hydrogeologic setting Chemical composition of contaminated plume	Climatic conditions Geographic conditions Surface water category Hydrogeologic setting Chemical composition of surface water	Climate Site-specific weather conditions Site topography Physical features Chemical composition of waste

contamination where electrical conductivities vary markedly from background levels, (3) locate trenches in which wastes may have been buried, and (4) to locate and define buried metallic objects. Such studies are generally less expensive than well installations. (This includes the costs for development, maintenance, sampling and priority pollutant analyses). In some geologic settings, geophysical investigations are the most suitable method for investigating groundwater flow paths. When a geophysical investigation points to a possible geologic anomaly or otherwise unrecognizable feature (natural or man-made), one or a few appropriately sited wells can be drilled to examine the subsurface directly; this saves the often unnecessary and expensive task of drilling many wells on a grid system to investigate the subsurface geology of the site. Geophysical techniques include

Ground Penetrating Radar (GPR), Electromagnetic Conductivity (EM), Electrical Resistivity Surveys, or Seismic Surveys.

It is important to understand that any geophysical method which is successful at one site may or may not have the same success at another site. There are many variables associated with all geophysical techniques as presented in Table 6. Someone with the experience to know the limitations of each of the techniques should be consulted prior to developing a large geophysical reconnaissance program.

Ground Penetrating Radar:

This technique uses high-frequency radio waves sensitive to interfaces between materials with differing electrical conductivities. These waves are

Table 3. Summary of Important Geologic Information (EPA 540/G-85/002)

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary*
Structural Features:			
<ul style="list-style-type: none">Folds, faults	Determine natural flow barriers or controls	Existing geologic maps, field surveys	Remote sensing, aerial photography, geophysical techniques
<ul style="list-style-type: none">Joints, fractures, interconnected voids	Predict major boundaries, avenues of groundwater flow	Existing geologic profiles, pump tests	Borehole logging and mapping, geophysical techniques (limited)
Stratigraphic Characteristics:			
<ul style="list-style-type: none">Thickness, areal extent, correlation of units,† extent (horizontal and vertical) of aquifers and confining units	Determine geometry of aquifers and confining layers, aquifer recharge and discharge	Existing geologic maps, observation wells	Borehole logging and mapping, geophysical techniques (limited)
<ul style="list-style-type: none">Mineral composition, permeability, and porosity, grain-size distribution, in-situ density, moisture content	Determine groundwater quality, movement, occurrence, productivity	Laboratory analysis, existing geologic literature	
Groundwater Occurrence:			
<ul style="list-style-type: none">Aquifer boundaries and locations	Define flow limits and degree of aquifer confinement	Existing literature, water resource atlases	Existing literature
<ul style="list-style-type: none">Aquifer ability to transmit water	Determine potential quantities and rates for treatment options	Pumping and injection tests of monitor wells	Borehole logging, regional water level measurements
Groundwater Movement:			
<ul style="list-style-type: none">Direction of flow	Identify most likely pathways of contaminant migration	Existing hydrologic literature	Water level measurements in monitor wells
<ul style="list-style-type: none">Rate of flow	Determine maximum potential migration rate and dispersion of contaminants	Existing hydrologic literature	Hydraulic gradient, permeability, and effective porosity from water level contours, pump test results, and laboratory analyses
Groundwater Recharge/Discharge:			
<ul style="list-style-type: none">Location of recharge/discharge areas	Determine interception points for withdrawal options, areas of capping	Existing site data, hydrologic literature site inspection	Comparison of water levels in observation wells, piezometers, lakes and streams
<ul style="list-style-type: none">Rate			
Groundwater Quality			
	Determine variability of loading to treatment options	Existing literature	Water balance calculations aided by geology and soil data
<ul style="list-style-type: none">pH, total dissolved solids, salinity, specific contaminant concentrations	Determine exposure via groundwater; define contaminant plume for evaluation of interception methods	Existing site data	Analysis of groundwater samples from observation wells, geophysics

*May be appropriate if detailed information is required or if it is the only method due to a paucity of published data.

Table 4. Summary of Basic Technologies and Data Needs to Modify the Degree of Hazard of Wastes

Waste Type	Form	Technology Options	Preliminary Technology Data Needs
Corrosive	Liquid	Chemical	pH Constituent analysis Oil and grease content Total suspended solids Total dissolved solids
		Biological	Gross organic components (BOD, TOC) Dissolved oxygen Nutrients analysis (NH ₃ , PO ₄ , NO ₃) pH Priority pollutant analysis ORP
Ignitable	Liquid	Thermal	Heat content Ash content Halogen content Moisture content Heavy metal content Volatile matter content
		Thermal	Heat content Halogen content
	Gas	Pretreat to get to treatable form by Chemical and Biological means	
	Solid	Biological	Gross organic components (BOD, TOC) Nutrient analysis (NH ₃ , PO ₄ , NO ₃) Priority pollutant analysis pH
		Thermal	Heat content Volatile matter content Ash characteristics Ash content Halogen content Moisture content Heavy metals content
Reactive	Liquid	Chemical	pH Constituent analysis
		Biological	Gross organic components (BOD, TOC) Dissolved oxygen Nutrients analysis (NH ₃ , PO ₄ , NO ₃) pH Priority pollutant analysis ORP
	Gas	Thermal	Heat content Ash content Halogen content Heavy metal content Volatile matter content
		Pretreat to get to treatable form by Chemical and Biological means	
	Solid	Biological	Gross organic components (BOD, TOC) Nutrient analysis (NH ₃ , PO ₄ , NO ₃) Priority pollutant analysis pH
		Thermal	Heat content Ash content Halogen content Heavy metal content Volatile matter content

Table 4. (Continued)

Waste Type	Form	Technology Options	Preliminary Technology Data Needs
Toxic-Inorganic	Liquid	Thermal	Heat content Volatile matter content Ash characteristics Ash content Halogen content Moisture content Heavy metals content
		Chemical	pH Constituent analysis Oil and grease content Total suspended solids Total dissolved solids
	Gas	Pretreatment required to get to liquid phase for chemical treatment or solid phase for solidification/stabilization	
Organics	Solid	Solidification/Stabilization	Solubility (in H ₂ O, organic) Solvents, oils, etc. Size distribution Constituent analysis
		Chemical	pH Constituent analysis Halogen content Total suspended solids heavy metals content
		Biological	Gross organic components (BOD, TOC) Dissolved oxygen Nutrient analysis (NH ₃ , PO ₄ , NO ₃) pH Priority pollutant analysis ORP
	Gas	Thermal	Heat content Ash content Halogen content Heavy metals content Volatile matter content
		Thermal	Heat content Halogen content
		Pretreat to get to treatable form by Chemical and Biological means	
	Solid	Biological	Gross organic components (BOD, TOC) Nutrient analysis (NH ₃ , PO ₄ , NO ₃) Priority pollutant analysis pH
		Thermal	Heat content Volatile matter content Ash characteristics Ash content Halogen content Moisture content Heavy metals content

Table 5. Important Physical Treatment Data Needs

Data Need	Purpose
For Solids	
Absolute Density	Density Separation
Bulk Density	Storage Volume Required
Size Distribution	Size Modification or Separation
Friability	Size Reduction
Solubility (in H ₂ O, organic solvents, oils, etc.)	Dissolution
For Liquids	
Specific Gravity	Density Separation
Viscosity	Pumping & Handling
Water Content (or oil content, etc.)	Separation
Dissolved Solids	Separation
Boiling Pt/Freezing Point	Phase Change Separation, Handling and Storage
For Liquids/Solid Mixtures	
Bulk Density	Storage & Transportation
Total Solids Content	Separation
Solids Size Distribution	Separation
Suspended Solids Content	Separation
Suspended Solids Settling Rate	Separation
Dissolved Solids Content	Separation
Free Water Content	Storage & Transport
Oil and Grease Content	Separation
Viscosity	Pumping and Handling
For Gases	
Density	Separation
Boiling (condensing) Temp.	Phase Change Separation
Solubility (in H ₂ O, etc.)	Dissolution

sent and received (usually) from the same antenna, with variations in the returning signals being recorded continuously. The resulting subsurface profile shows features such as bedding, voids and fractures. There are depth limits to this technique, with signal attenuation becoming more important at depths where subsurface materials have low electrical conductivities, i.e., where pore fluids are present in quantity. What this means is that optimal conditions for this technique are sandy or rocky soils in the vadose zone or bedrock with low permeability where water is not permanently present. Clay-rich sediments (which by their nature retain water more than most sediments) and otherwise damp or saturated sediments will generally yield poorer results. However, reliable data are obtainable in settings where pore fluids have a low specific conductance, e.g., where significant amounts of petroleum products are present. Ground penetrating radar gives the highest resolution among the various techniques discussed herein, and a radar survey can be done relatively quickly at hazardous waste sites.

Electromagnetics:

The electromagnetic method measures electrical conductivity values of subsurface materials. Where pore fluids are present, it is their conductance values that are measured. A transmitter emits an electromagnetic field that sets up induced eddy currents, which are intercepted by a receiver, producing an output voltage that is related to subsurface conductivities. Paralleling the results obtained with radar, electromagnetic methods reveal changes in soil conductivity which are normally related to pore fluids. For example, in instances where leaking drums were buried in shallow trenches, the contaminated zone contrasted sharply with surrounding sediments. Because this technique produces data in conductivity units directly, the data can be used in the field immediately after the survey. This can allow for quick, "best-educated guess" decisions if necessary.

Table 6. Geophysical Techniques, Their Application and Limitations at Hazardous Waste Sites (Johnson, 1986)

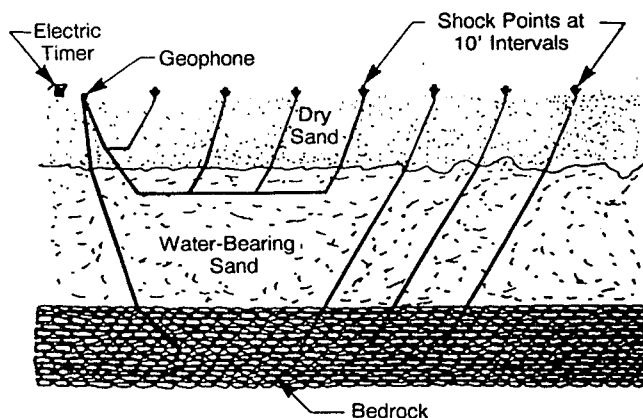
Technique	Technology Description	Utilization at Hazardous Waste Sites	Limitation on Application
Ground Penetrating Radar (GPR)	An electromagnetic pulse is sent into the ground. The reflected pulses are detected by an antenna held at the surface of the ground.	In real-time, shallow earth profiles of dielectrical discontinuities related to subsurface conditions such as moisture content, lithology, bedding, voids, fractures, man-made objects. Can be used to detect buried plastic containers and areas of excavation boundaries.	<ul style="list-style-type: none"> ● Adverse soil conditions – Radar waves will not effectively penetrate damp, low-resistance clay or other conductive material. ● Improper antenna – Several frequencies should be tried before selecting the optimum frequency and antenna. ● Adverse surface conditions – Grooming of the surface may be required. Long grass and rough ground cause problems with radar penetration and patterns. Surface and subsurface metal can distort the GPR record. ● Improper calibration – Depth is difficult to derive from a single antenna receiver unless a specific target can be identified.
Electromagnetic (EM) Conductivity	Measures the electrical conductivity of materials in microohms over a range of depths determined by the spacing and orientation of the transmitter and receiver coils, and the nature of the earth materials.	Delineates areas of soil and groundwater contamination and the depth to bedrock or buried objects. Surveys to depths of 50 to 100 ft are possible.	<ul style="list-style-type: none"> ● Power lines, underground cables, transformers and other electrical sources severely distort the measurements. ● Low resistivities of surficial materials makes interpretation difficult. The top layers act as a shunt to the introduction of energy into lower layers. ● Capabilities for defining the variation of resistivity with depth are limited. ● 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, or where chemicals have been spilled on the surface, or where clay soils are present, it is probably not worth the effort to conduct the survey.
Seismic Refraction (SR)	Induced compression waves are reflected at the interface of the subsurface elements and refract differently based on the properties of the new medium of propagation.	Estimates the depth of bedrock, rock strength (density), depth to saturated soil or rocks and soil layering in general.	<ul style="list-style-type: none"> ● Fill material must be evaluated with extreme caution. Substantially more shot locations should be made than needed for a conventional survey. ● Industrial sites produce a lot of background noise, and it is necessary to utilize sources of energy more powerful than for normal survey work. ● Correlating data from site borings are required to obtain meaningful results from interpretations of the data.
DC Resistivity	Measures the voltage drop between two electrodes in the ground after an electric current has been put into the ground between two other electrodes.	Used to locate fractures in the bedrock that act as conduits for the contamination in otherwise impervious strata.	<ul style="list-style-type: none"> ● The Wenner array should not be used unless the expected ground conditions are fairly simple. The Schlumberger array is less sensitive to lateral resistivity variations. ● Meaningful resistivity results cannot be expected on top of the area of buried debris (landfill), dry sand, frozen ground, or near fences, or railroad tracks and underground pipes. ● The resistivity survey cannot interpret information from a horizon beneath an aquifer. ● Contour maps of apparent resistivity can be misleading. Electrode spacing should not be considered to have a linear relationship with depth of penetration.
Magnetometry (MAG)	Measures the intensity of the earth's magnetic field and local magnetic anomalies. By electronically filtering out the earth's magnetic field and nulling the instrument, the local magnetic anomalies created by ferro-magnetic objects can be qualified.	Metal can be detected to depths up to 60 ft. Frequently a gradiometer, basically two magnetometers in one with the sensors at different levels, is more efficient than the single sensing unit.	<ul style="list-style-type: none"> ● The most effective survey lines orient N/S. ● Readings every 10 ft are needed on survey lines 30 ft apart. ● Surface ferrous items should be noted. ● Many anomaly patterns can exist due to other site activities than waste disposal. ● Anomaly patterns of a gradiometer are more difficult to interpret than those of the magnetometer.
Metal Detection (MD)	MD measures instrument responses to deposits of ferrous and nonferrous metals up to 10 to 20 ft deep.	Detection of high-density deposits in shallow depths. Good inexpensive preliminary survey tool.	<ul style="list-style-type: none"> ● Background conductivities greater than 40 millimhos/meter impairs results. ● Wet clay soils impair results.

Because most groundwater contamination problems involve anionic/cationic species or organic chemicals, a change in background conductance levels will occur when a significant amount of contaminant is present in the subsurface. In the case of polar species (such as heavy metals, nitrates, chlorides, and other electrolytes) the specific conductance will, in most settings, be increased greatly over background levels. With organic contaminants such as nonpolar chlorinated solvents, specific conductance levels will decrease. In either case, an electromagnetic survey will commonly be able to detect the contaminant plume, define its boundaries and, in some cases, indicate the flow direction.

Resistivity

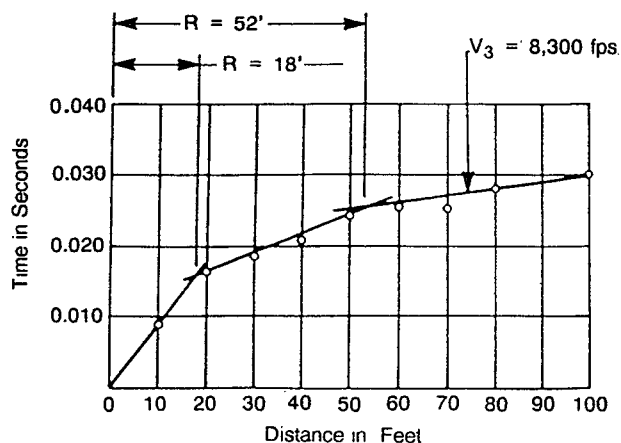
These surveys measure the electrical resistivity of subsurface materials, which is just the opposite of the electromagnetics survey. As one might expect, the advantages and disadvantages of each method are not the same. Resistivity methods use a pair of electrodes at the ground's surface to set up an electrical current in the subsurface, and the resultant voltage is measured by a second pair of electrodes. Resistivity is then calculated using site-specific variables in a standard equation. The effectiveness of a resistivity survey is basically dependent on pore fluid composition, as with electromagnetics, and the results can be used in a similar way. For example, the survey can be used to define the boundaries of a contaminant plume or to establish subsurface stratigraphic relations (Figures 2a and 2b).

Figure 2a Boundaries of a contaminant plume (Universal Oil Prod., 1972).



A comparison of resistivity and electromagnetic techniques (resistance versus specific conductance) shows that resistivity surveys are slower because the technique is necessarily limited to measurements at the fixed electrode points, which must be moved for each new survey. Electromagnetic surveys are not limited by fixed points. Also, certain applications of resistivity methods are best suited for sites where the

Figure 2b Subsurface stratigraphic relationship (Universal Oil Prod., 1972).



stratigraphic column is fairly uniform over the entire area. Resistivity surveys, however, are generally more effective than electromagnetics in profiling vertical variations in the subsurface. Furthermore, results of resistivity can be evaluated in the field qualitatively or semi-quantitatively. An additional capability of resistivity is that a first approximation of lithologic compositions can be made, particularly when outcrops are lacking in an area and wells are widely separated or absent altogether.

Seismic Refraction

This technique measures the travel time or velocity of seismic waves to map depths to and thicknesses of particular stratigraphic units or other significant layers (e.g., the water table or the base of landfills and trenches) in the subsurface. This is not the same as the seismic reflection technique commonly used in oil and gas exploration. The seismic reflection technique is ineffective at the relatively shallow depths in which contamination occurs at most hazardous waste sites. Seismic waves are sent out by introducing energy at the surface and recording direct and/or refracted waves with geophones spaced at regular intervals (Figures 3a and 3b). This method is inherently susceptible to severe disturbance by stray vibrations, which can be set up by nearby footsteps, cars, trains, etc., and the investigator must be aware of the potential problems such vibrations may cause in the data.

Seismic studies are very useful when information is lacking on subsurface stratigraphy, or when the depth to bedrock, the water table, a particular bed or formation, or some other layer in the subsurface must be determined without drilling. Seismic lines can be set up to produce stratigraphic cross sections and they can be a very useful "non-invasive" inves-

tigative technique, particularly if correlated with a core-measured section or geophysical well log. The lack of "hard" stratigraphic data from a core, well log, etc., means that the interpretation of the "soft" seismic data is much more subjective. This may not be a problem in a small study area, but when the goal is subsurface stratigraphic interpretation over a large area, the results would probably be considered speculative until a well was drilled and logged or an outcrop measured, and this stratigraphic information was convincingly correlated with the seismic data. Once again, note the importance of mapping the site geology to determine field relations of the various strata present. Without this information, much of the interpretation of information gathered from seismic studies is necessarily speculative.

Figure 3a Cross-section of seismic refraction measuring technique (Zhody, 1974).

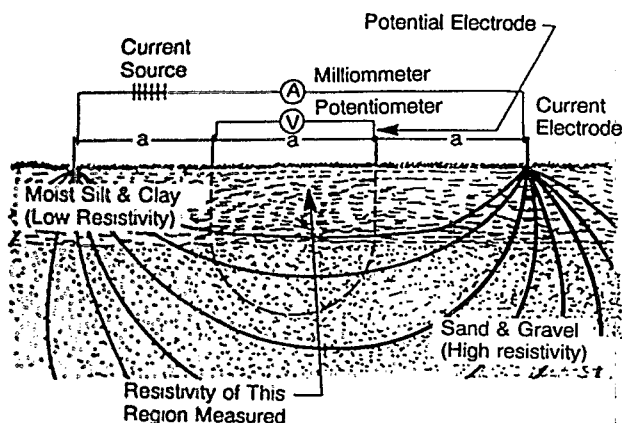
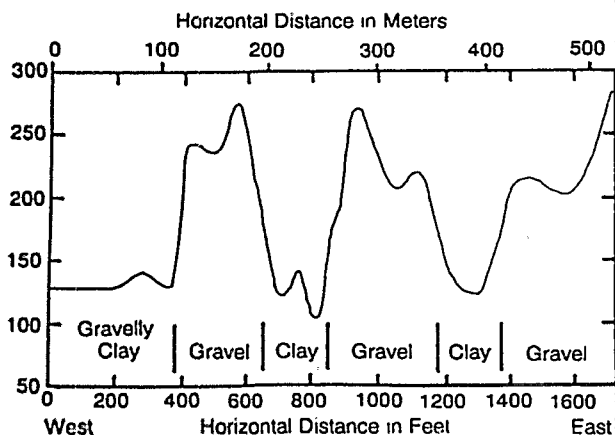


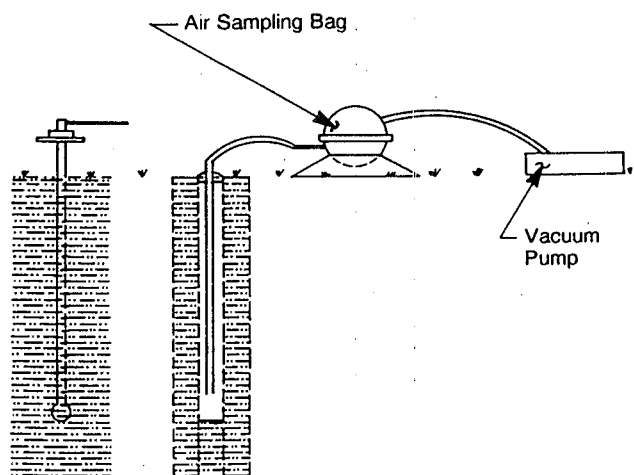
Figure 3b Log of seismic refraction results (Zhody, 1974).



Soil Gas Monitoring

VOCs on the "surface" of groundwater volatilize into the voids in the soil above the groundwater. Soil gas collection and sampling procedures have been developed that are simple and quick to implement (Lappala, 1984; Quinn, 1985; Nadeau, 1985). In one method as shown in Figure 4, a small diameter (1-in.) steel probe is inserted to a depth of 3 feet. A vacuum pump pulls the VOC that is present between the interspaces or voids of the soils into a sample tube. The sealed tube is taken to a laboratory for analysis by Gas Chromatography (GC). The sample train is decontaminated before use in the next probe hole by pumping ambient air through the system. A portable photoionization detector (PID) gas chromatograph can be used in the field prior to putting the sample into the collection tube. By first passing a sample through this device, a quick determination of the presence of VOCs can be made. If there is no reading, then no sample need be analyzed in the laboratory.

Figure 4. Soil vapor probe and sampling train (Nadeau, 1985).



As shown in Figures 5a, 5b, 5c and 5d, the soil gas sampling procedure can quickly produce isopleths of VOC concentrations over a large site and indicate possible source areas. While not exactly analogous to the VOC concentrations in groundwater, the results can be utilized to develop a borehole and monitoring well program with a minimum number of wells because of this prior knowledge of the site conditions. The soil gas sampling procedure is low cost, produces low site disturbance and can be used at sites with difficult access.

Detection limits of 0.0001 to 0.01 mg/P in soil samples and 0.1 to 1.0 mg/l in water samples have been reported. Lappala (1984) reported the results of repeated sampling on successive days at a

southwestern United States site using these soil gas sampling techniques. The results of successive days' samples showed no significant difference by Student's "t" Test. However, Karably (1987) reported significant variations in soil gas sample point readings (i.e., magnitude of VOC detected) over an extended time period caused by environmental variables. However, the general trend of contaminant levels and plume geometry were roughly the same. Soil gas concentrations were found to be affected by temperature and infiltrating groundwater.

A second factor affecting the repeatability of the soil gas sampling techniques was the length of time to draw the sample at each station. Karably (1987) reported that results of repeated sampling at the same station suggest that a specific volume of soil gas must be evacuated to obtain a representative sample, and that this volume would differ among hazardous sites. This required volume would need to be determined at each site as part of the sampling protocol. Results and effectiveness have been found to be sensitive to repeated spill incidents on the same site and to fluctuations of the groundwater table. Sites with tight, saturated clay layers or an expected contaminated layer below a clean layer of groundwater are not good applications for soil gas sampling (Lappala, 1984). A sampling probe length of 3 feet has been used on sites with groundwater down to 36 feet, while a length of 10 feet is needed for groundwater down to 100 feet. If the detected concentration decreases with depth, then the source of the VOC is a surface spill. If the concentration increases, this indicates that the VOC is on the surface of the groundwater. The sampling procedure has limited usefulness for deep groundwater (75 to 100 feet).

For air sampling of unknown contaminants, a multistage tube was developed to provide a quick profile of organic compounds (Turpin, 1984). Solid sorbent media require minimal processing to produce a suitable sample for injection into GC/MS analytical equipment, a rapid qualitative and quantitative device for characterization of unknown mixtures. This procedure reduces the number of air samples needed, improves turnaround time, and identifies a wide variety of chemicals in the screening process. The sample is collected in a two-stage tube consisting of Tenax-GC packing in the first tube and Chromosorb® 102 sorbent in the second. Some chemicals such as tricresyl phosphate, isopropyl alcohol, chlordane, Aroclor 1254, and naphthalene were not collectible by this tube configuration.

Use of Surrogates

During a preliminary investigation, much of the expense associated with analytical activities can be reduced by using surrogate or good indicator parameters. These are typically nonspecific.

Examples would be: total organic carbon, total organic halogens, specific conductance or, if dealing with gases, organic volatile measurements. It should be emphasized that these analyses measure a class or a group of compounds and may not directly quantify the specific compound or contaminants of concern. Care must be exercised when correlating these nonspecific measurements with the total movement of the contaminant.

Core Sampling

To make the most of monitoring well installations, it should be decided if continuous coring with core recovery should be performed during well drilling activities. The study of cores is the best way to examine rocks in the subsurface, and if there are unresolved questions about porosity, hydraulic conductivity, fracturing, etc., the detailed lithologic log produced from core logging will often provide answers. Cores give a more complete picture of the subsurface geology and contaminant location than do cuttings alone, and therefore, coring is preferred.

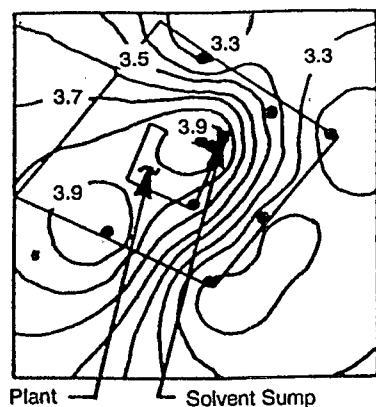
Monitoring Well Networks

Pumping tests or single well tests are probably the most utilized tool to determine the aquifer properties. There are a number of different type tests, but as with any other type of testing program, selecting the sampling point(s) is critical in order to obtain good results. An effective preliminary survey can produce significant cost savings by specifying the optimum locations for a minimum number of required wells. Before any site-specific groundwater sampling is done, soil and waste characterization should be completed.

When groundwater contaminant plumes are suspected of having significant depth as well as lateral distribution, a three-dimensional array of monitoring points is needed to identify and characterize such plumes. Thus, groundwater data must be obtained from a number of different locations and from a number of different depths at each location. As a result, either a large number of drillholes are required, each with separate instrumentation installed, or instruments must be combined and installed at multiple levels in each of a smaller number of drillholes.

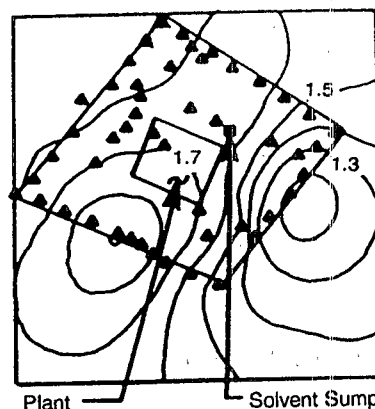
Several downhole sampling devices have been developed to sample at discrete and multiple levels within the well. Discrete sampling can be utilized to identify the location for the well screening to assure extraction of the contaminant during pumping. The sampler can be lowered into a borehole to increasingly lower depths until the proper level is identified. The sampler is then removed and the well is developed for extraction. If the well were being developed as a monitoring well, then the sampler can

Figure 5. Comparison of TCE and TCA concentration distribution by groundwater and soil gas samples, southwestern U.S. study (Lappala, 1984).



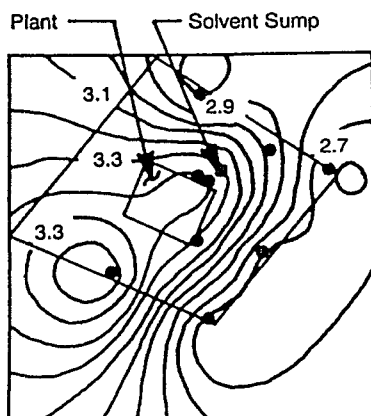
Log of TCE in Groundwater

Figure 5a.



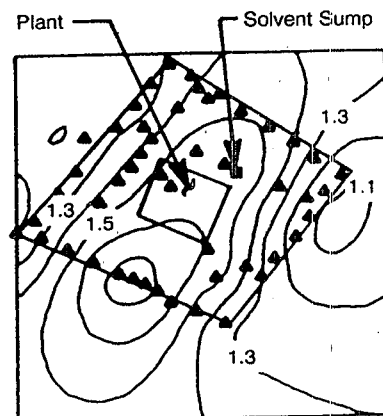
Log of TCE in Soil Gas

Figure 5b.



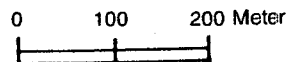
Log of TCA in Groundwater

Figure 5c



Log of TCA in Soil Gas

Figure 5d.



- Legend:**
- Monitoring Well
 - ▲ Soil Gas Probe
 - 3.1 Log of TCE or TCA Concentration in Groundwater
 - 3.1 Log of TCE or TCA Concentration in Soil Gas

be left in place. A multiple level sampler can be used to take many samples over the depth of the well without having to be moved if such sampling is required.

Conceptual Model

Upon completion of both the preliminary and detailed site investigation, a conceptual model can be prepared. A conceptual model is essentially a site model which includes all of the information that has been acquired for the site from both preliminary and detailed investigations, as well as other investigations not directly related to the site. The conceptual model can be anything from simple diagrams to detailed computer simulations, depending upon the complexity of the site. The model must be continually updated to include new information as it is developed.

Once the conceptual model is operating, it can be utilized to help develop a technically sound, cost-effective recovery and treatment system. Potential uses for a conceptual model include provision of continual updates of project developments, provision of a yardstick to measure what has been done and what needs to be done, and helping prioritize areas for Corrective Action. Ultimately, the principal use for a conceptual model is to help determine what Corrective Actions or alternatives are applicable to the site.

Laboratory and Bench-Scale Studies

Bench- or pilot-scale studies are necessary to demonstrate the ability of a technology to effectively treat a specific waste. Waste characteristics vary from site to site and because of this, the effect of a treatment technology with that particular waste may not be known, given the site-specific factors and conditions. Also, the proposed treatment technology may be new or unproven.

Thus, bench or pilot studies are necessary to avoid technology misapplication in the field. The loss of time in treatment or the requirement to provide additional treatment for the waste is very expensive. Therefore, the relatively small costs and time needed for these studies make them useful tools in treatment selection. Bench-scale treatability studies for demonstrated technologies can cost between \$10,000-\$50,000 and take up to 6 weeks. Demonstrated technologies are those for which the major design parameters and treatment efficiencies are well understood. Innovative (and some biological processes) will require substantially more time (4-16 weeks) and money (\$25,000->\$200,000). These are estimates, and actual time and costs are going to depend on what kind of technology is under consideration.

Pilot-scale studies for demonstrated technologies can cost from \$25,000 to more than \$100,000 and typically require 2-12 weeks. For innovative technologies, the cost for pilot testing can start at \$100,000 and exceed \$1,000,000 and require 3 to 12 months.

Aside from size considerations, the primary difference between bench-scale and pilot-scale work is that bench-scale tests are conducted in the laboratory; pilot-scale testing is usually carried out on the site. Pilot tests are subject to a whole range of problems, such as siting, health and safety, obtaining clearances, installation and operation. However, the data obtained from pilot-scale tests are much more appropriate and useful because they reflect what is actually occurring in the field.

The choice of the kind of testing (bench or pilot-scale) to be performed is going to hinge on the balance between the level of certainty that the technology is going to work (and be effective for the site) against the risk of failure if the technology does not work for the unique mix of contaminants and contaminated media (air, water, soils, sediments) found at that site. The risks of failure include the cost and time needed to perform another test or to implement another technology if the first one selected fails. Obviously, pilot-scale studies may not be needed if there is a high level of certainty that the particular technology will work (i.e., there is a low risk of failure). Pilot-scale studies also may be unnecessary if there is going to be very little cost or time penalty for identifying a new treatment system, given failure of the first. On the other hand, if there is a low level of certainty that the technology is appropriate and there is a very high risk of failure, one needs to carefully consider that it may be more prudent to spend the time and money for bench-scale testing. Pilot-scale testing, without prior bench-scale testing, should be employed only when there is a moderate level of certainty that the technology is going to be effective and there is only a moderate risk of failure.

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Chapter 3

Containment Options

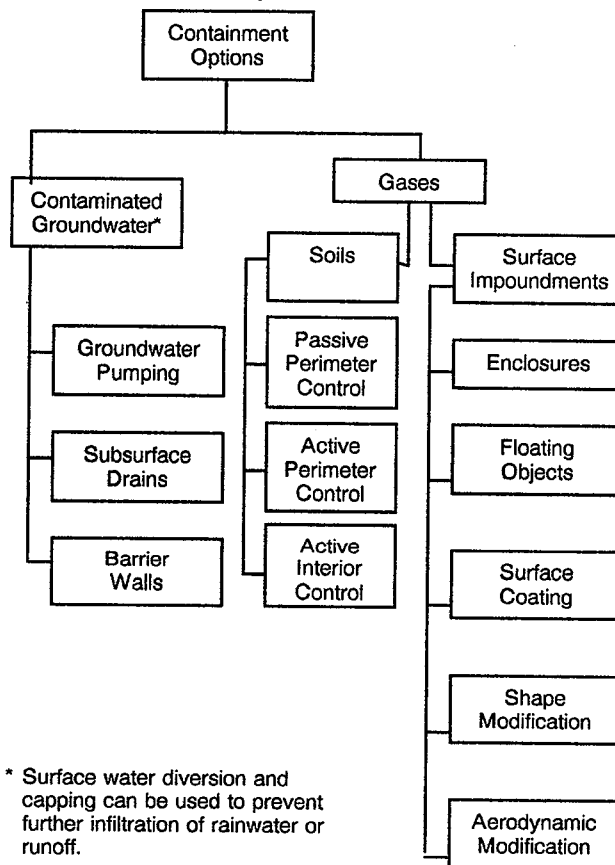
If hazardous wastes or hazardous constituents are found to be migrating from a RCRA-regulated facility, an initial response might be directed toward implementation of methods to control their spread. Once the site investigation provides sufficient information about the nature and extent of the contamination and the medium in which the contaminant is located, actions to limit the spread of the contaminant can be developed, if deemed necessary. Note that the containment technology selected depends upon the medium in which the contaminant is found and the general containment options available for common situations encountered are shown in Figure 6. These situations include contaminated groundwater and gaseous emissions from landfills or surface impoundments.

Groundwater Containment

Contaminants from a hazardous waste site can enter the groundwater system through a variety of mechanisms: (1) surface water infiltration, (2) groundwater passage through the waste, and (3) liquid waste flow through permeable soil. Control of contaminant migration involves containment of the contaminated groundwater plume and the prevention of further dissolution of contaminants by water entering the waste area. Infiltration of rainwater to the contaminated medium can be controlled by capping and surface water diversion techniques. A more difficult problem arises when trying to contain the movement of uncontaminated groundwater through a waste or of a plume of contaminated groundwater. However, before a specific containment strategy can be selected and subsequently located in the field, it is important to have a good understanding of the hydrogeologic setting and the subsurface behavior of the contaminants.

With an understanding of the site geology and hydrology and the behavior of the contaminants in the subsurface, the selection of containment/recovery technology can begin. Typical ways to contain and/or recover contaminated groundwater plumes include groundwater pumping, subsurface drains and barrier walls. Barrier walls are a passive option typically aimed at containment whereas groundwater

Figure 6. Containment options.



pumping and subsurface drains can be used to control pollutant migration as well as to extract contaminated groundwater for subsequent treatment.

Groundwater Pumping

Groundwater pumping can be used to manipulate and manage groundwater for the purpose of removing, diverting, and containing a contaminated plume or for adjusting groundwater levels to prevent plume movement. For example, pumping systems consisting of a series extraction wells located directly down-gradient from a contaminated source can be

used to collect the contaminated plume. Water can also be injected into the subsurface to move the plume away from an area that must be protected, such as a domestic drinking water source (Figure 7a and 7b). The success of any contaminant capture system based upon pumping wells is dependent upon the rate of groundwater flow and the rate at which the well is pumped. Thus, the zone of capture for the pumping system must be established.

Figure 7a. Containment using extraction wells (U.S. EPA, 1985).

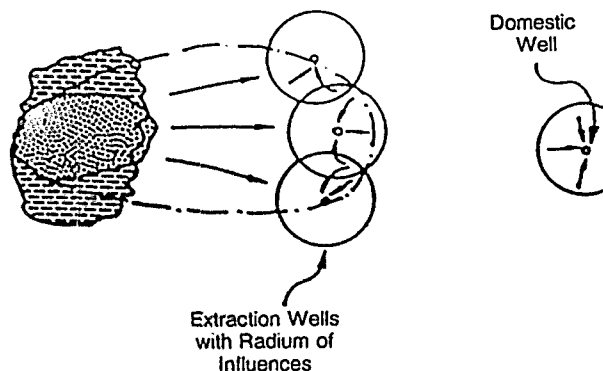
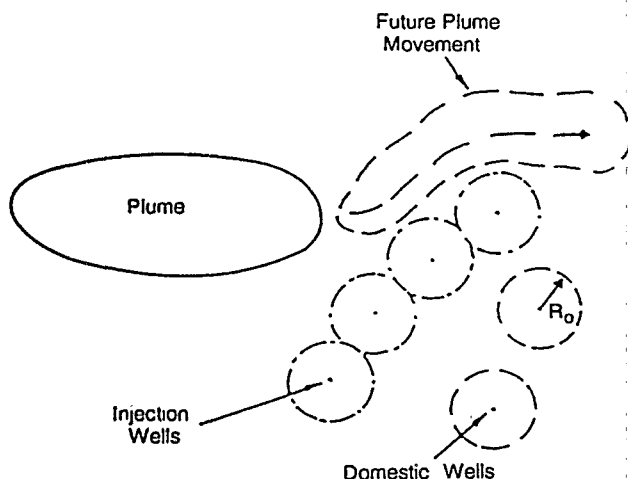


Figure 7b. Plume diversion using injection wells (U.S. EPA, 1985).



Corrective Action Application

The Fairchild Camera and Instrument Corporation site in South San Jose, California, proved to be a complex and difficult groundwater contamination

cleanup action (U.S. EPA, January 1987). Over 43,000 gallons of organic chemicals were lost into the soil, contaminating four aquifers beneath the site. Groundwater in the shallow aquifers was initially contaminated by the chemicals. Subsequently, contaminants migrated into the lower aquifers through interconnecting sand beds, existing wells, and slow seepage through separating strata. The first action taken for plume containment was the installation of an extraction well to create a zone of influence to draw the plume back. The initial pumping rate was 500 gpm, but this was increased to 1500 gpm when the lower rate failed to contain the plume spread. To further control the spread of the plume, three rows of extraction wells were installed near the source of the contaminant. The combined pumping dewatered two aquifers, but left the contaminant behind in the unsaturated soil. Subsequently, contaminants continued to migrate to lower aquifers. Finally, the source was contained with a 3500-ft long, 70 to 140-ft deep, 3-ft wide slurry wall.

Subsurface Drains

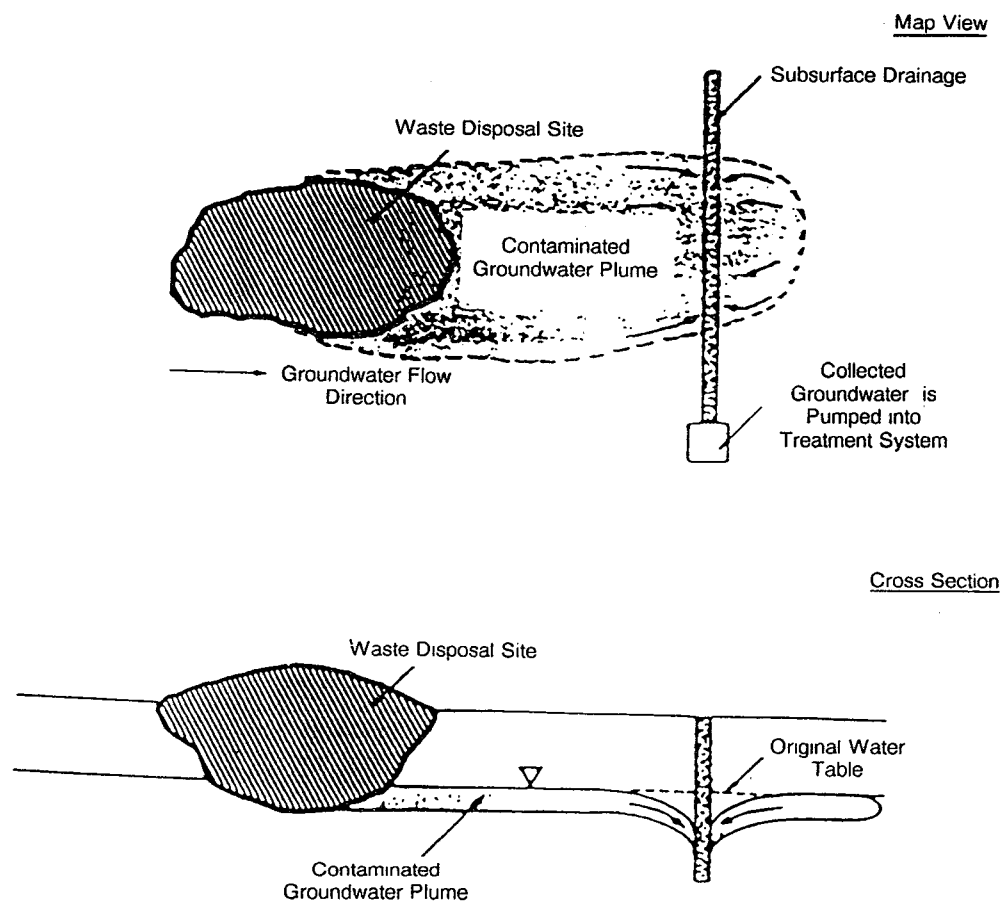
Pumping techniques represent an aggressive approach which requires ongoing maintenance and operation throughout the life of the Corrective Action. By contrast, subsurface drains (and barrier walls, described below) represent a passive design which do not require a high level of ongoing maintenance. Subsurface drains are most useful in preliminary containment applications for controlling pollutant migration while a final treatment design is developed and implemented. They also provide a measure of long-term protection against residual contaminants following conclusion of treatment and site closure.

Subsurface drains are essentially permeable barriers designed to intercept the groundwater flow. The water must be collected at a low point and pumped or drained by gravity to the treatment system (Figure 8). Subsurface drains can also be used to isolate a waste disposal area by intercepting the flow of uncontaminated groundwater before it enters into a contaminated site.

Corrective Action Application

The use of a drain system permits the quick construction of a collection/removal system which also serves as a barrier for leachate from large, shallow sites. At the Sylvester hazardous waste site in Nashua, New Hampshire, a groundwater interception and recirculation system was installed as a method to retard further spread of the leachate plume until a remedial cleanup action could be implemented. The system was operated for 1 year until a containment wall and cap were constructed over the 20-acre site (McAneny, 1985).

Figure 8. The use of subsurface drainage to contain a leachate plume (U.S. EPA, 1985).



Barrier Walls

Low permeability barriers are used to direct the uncontaminated groundwater flow around the disposal site or to prevent the contaminated material migrating from the site. Figures 9a, 9b and 9c illustrate typical configurations for barrier walls. Barrier walls can be made of a wide variety of materials as long as they have a lower permeability than the aquifer. Typical materials include mixtures of soil and bentonite, mixtures of cement and bentonite, or barriers of engineered materials (sheet piling). A chemical analysis of wall/contaminant compatibility is necessary to the final selection of materials. The installation of a low permeability barrier usually entails a great deal of earth moving, requires a significant amount of land area, and is expensive. However, once in place, they represent a long-term, low maintenance system. Once in place, active gradient controls (i.e., pump and treat) required by some installations will add to the long term operating costs of these systems.

Corrective Action Application

At one Superfund site, a slurry wall was placed around a landfill containing municipal waste and industrial hazardous wastes (solid and liquid). In addition to installing the slurry wall, a cap over the site was constructed simultaneously. Due to the onset of winter, the capping of the site had to be halted. During the subsequent winter months, an extraordinary amount of rainfall was experienced. The area within the slurry wall began to fill with water (the bathtub effect). A pumping and treatment system had to be installed to reduce and treat the water which collected within the slurry wall. Some portions of the slurry wall required repair due to the large hydraulic gradient produced by the high water levels inside the wall (U.S. EPA, 1987).

This case serves to point out the importance of maintaining a constant hydraulic gradient on the inside and outside of a slurry wall. This can also become a factor if slurry walls are used with groundwater pumping systems (extraction wells). Then water must be reinjected to maintain a

Figure 9a. Plan of downgradient placement (Spooner et al., 1984).

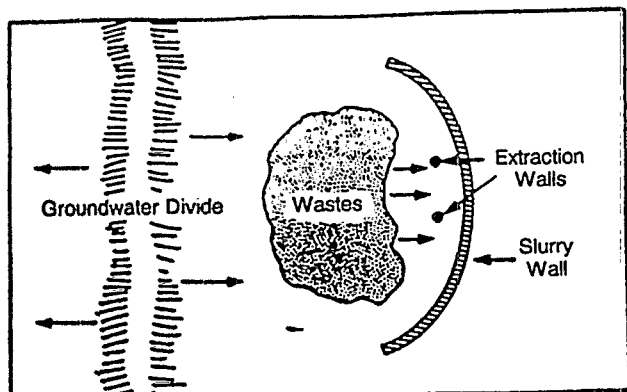


Figure 9b. Plan of upgradient placement with drain (Spooner et al., 1984).

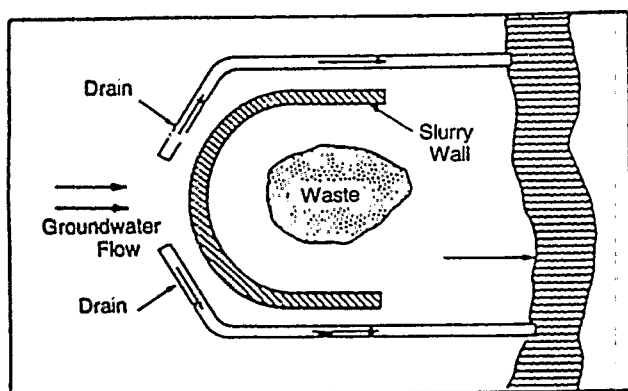
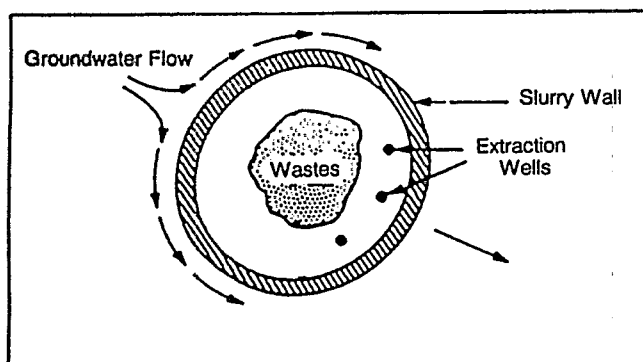


Figure 9c. Plan of circumferential wall placement (Spooner et al., 1984).



relatively constant hydraulic gradient on both sides of the slurry wall.

Containment and Control Options for Gaseous Wastes from Soils

Gaseous wastes may introduce an additional range of problems which must be addressed in the design of a containment plan. Gaseous wastes will migrate vertically or horizontally along the path of least resistance. Control systems fall into three general categories: (1) passive perimeter gas control systems, (2) active perimeter gas control systems, and (3) active interior gas collection/recovery systems. All of these systems assume the installation of a cap to prevent vertical escape of gaseous wastes.

Passive Perimeter Gas Control Systems

Passive perimeter gas control systems are designed to alter the path of contaminant flow through the use of trenches or wells, and typically include synthetic flexible membrane liners (FMLs) and/or natural clays as containment materials. The membrane is held in place by a backfilled trench, the depth of which is determined by the distance to a limiting structure, such as groundwater or bedrock. A permeable trench installation functions to direct lateral migration to the surface, where the gases can be vented (if acceptable) or collected and conveyed to a treatment system (Figure 10a and 10b).

Corrective Action Applications

At the Lipari Landfill site in New Jersey, the gas venting system installed in 1983 consisted of two underground 4-inch (10-cm) perforated PVC pipes and five vent risers. Two parallel PVC pipes were installed 200 feet apart prior to cap emplacement during the period of wall construction and were placed about 3 feet beneath the finished grade. The vent risers were connected to the buried manifold pipes and consisted of open pipe installed perpendicular to the underground pipes and the ground surface. Filters were not attached to the riser exit points (U.S. EPA, 1987).

Active Perimeter Gas Control Systems

An active perimeter gas control system can have any of the same configurations as a passive perimeter system with the addition of any combination of gas extraction wells, gas collection headers, vacuum blowers or compressors. Their ultimate purpose is to direct the gas to a treatment or utilization system.

Active Interior Gas Collection/Recovery Systems

Active interior gas collection and recovery systems are designed to supplement capping and to prevent

Figure 10a. Passive gas control using a permeable trench (U.S. EPA, 1985).

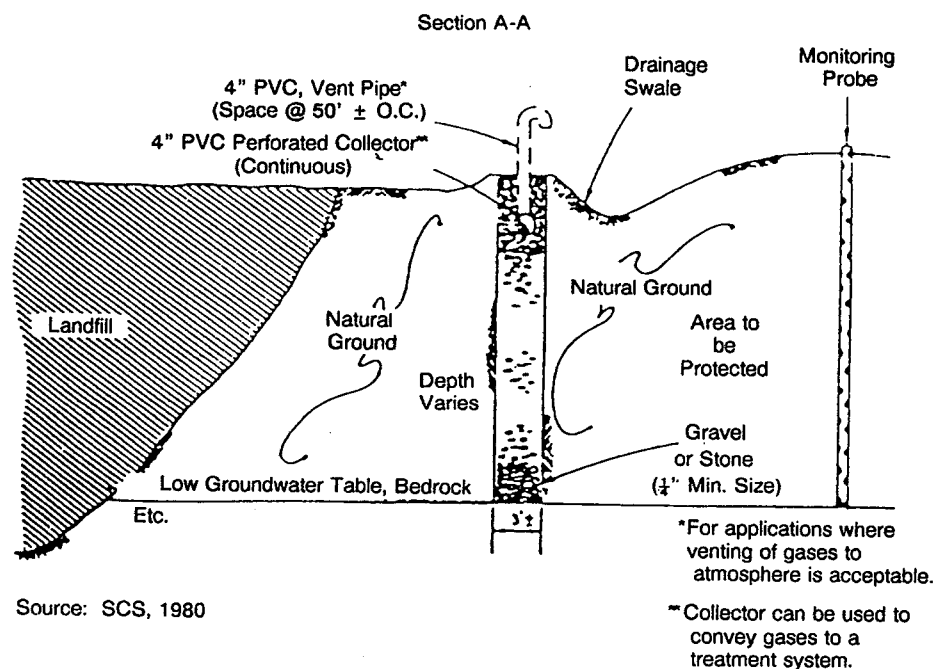
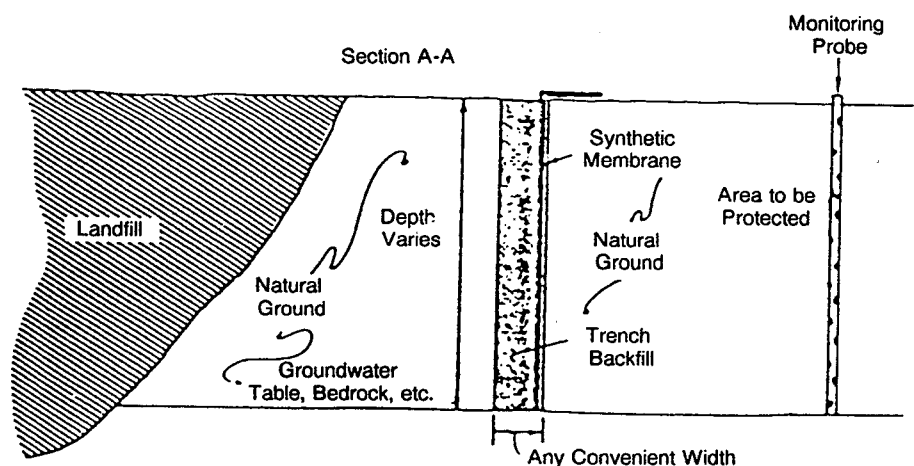


Figure 10b. Passive gas control synthetic membrane (U.S. EPA, 1985).



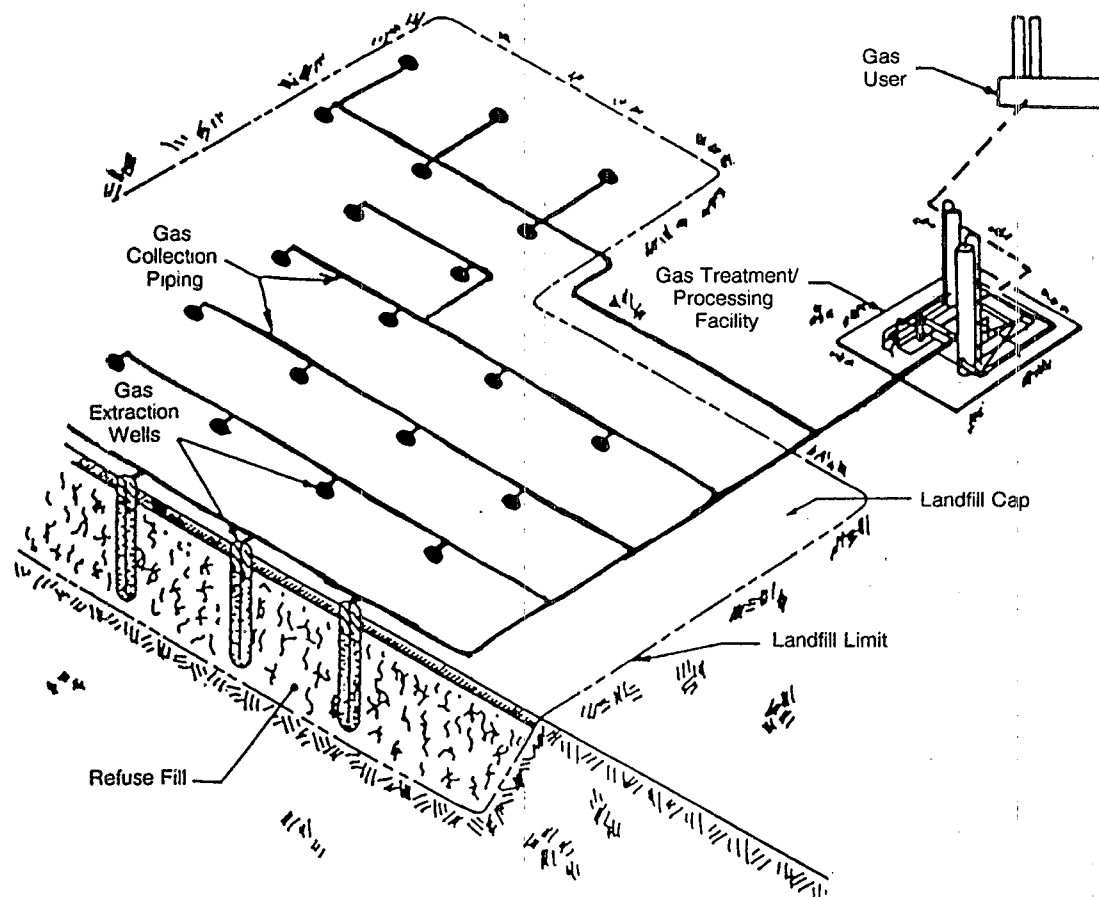
Source: SCS, 1980

lateral gas migration. Gas extraction wells are a principal component of such systems. Active interior systems are quite similar to perimeter gas control systems and differ primarily in terms of scale (Figure 11). Active interior systems represent the most effective means of containing and controlling gaseous wastes and can be designed using conventional equipment with little time required for implementation. The reliability of such systems is limited by their dependence on mechanical and electrical components.

Corrective Action Application

At the Taylor Road landfill (originally intended for the disposal of municipal refuse only), unknown quantities of hazardous wastes from industrial and residential sources were deposited. During the period when the landfill was active, soil and groundwater samples collected at the site were found to contain concentrations of volatile organic compounds and metals above acceptable safe drinking water standards. Analysis of samples collected from private drinking water wells indicated that contamination

Figure 11. Gas collection/recovery system (U.S. EPA, 1985).



was also present down-gradient from the Taylor Road site. After the Taylor Road site was closed, methane gas was detected off-site near adjacent residences.

To handle the methane gas generated from the 42.5-acre site, an active interior gas collection system was installed as shown in Figure 11. The installation consisted of 42 recovery wells, a gas collection header system, condensate traps, blower station and a flare station. In addition, a methane monitoring system consisting of thirty-two 2-inch wells was installed around the site (U.S. EPA, 1987).

Methods to Control Releases from Surface Impoundments

Surface impoundments are a significant source of gaseous emissions which can be controlled through a wide range of strategies. These approaches include enclosure, covering the surface with floating solid objects, the addition of surface coatings, shape modification and aerodynamic modification.

Documentation of specific application of these technologies is limited.

Enclosures

An enclosure is usually an air-supported structure which permits the collection and treatment of gaseous wastes produced by surface impoundments. Enclosures are susceptible to wind damage and can be harmed by the wastes they cover. Subject to these limitations, control effectiveness approaches 100 percent (University of Arkansas and Louisiana State University, 1985).

Floating Objects

A variety of containment strategies employ floating solid objects to control the rate of gaseous emissions from surface impoundments. These include: synthetic membrane covers, rafts, and hollow plastic spheres. Synthetic membrane covers are feasible where the out-gassing of volatiles due to biological activity is not expected. Selection of the liner material must be

based on permeability and resistance to the gases to be contained. Membrane covers are subject to damage by weathering or by contact with wastes. They are similar to enclosures in effectiveness, i.e., greater than 90 percent (University of Arkansas and Louisiana State University, 1985).

Rafts are designed to restrict the surface area exposed to air so as to reduce oxygen absorption. They are subject to damage by direct waste contact and can achieve efficiencies of up to 90 percent.

Floating hollow spheres are made of polypropylene with projections to prevent rotation. They restrict oxygen absorption and reduce emissions with an effectiveness of 80 to 90 percent. High winds can pose serious problems by blowing the spheres away (University of Arkansas and Louisiana State University, 1985).

Surface Coatings

Floating oil layers and surfactants constitute a liquid alternative to floating solid objects. An immiscible liquid floating on the surface has been found to be effective in reducing air emissions by up to 90 percent. However, windy conditions can result in a 50 to 80 percent loss of efficiency (University of Arkansas and Louisiana State University, 1985).

Shape Modification

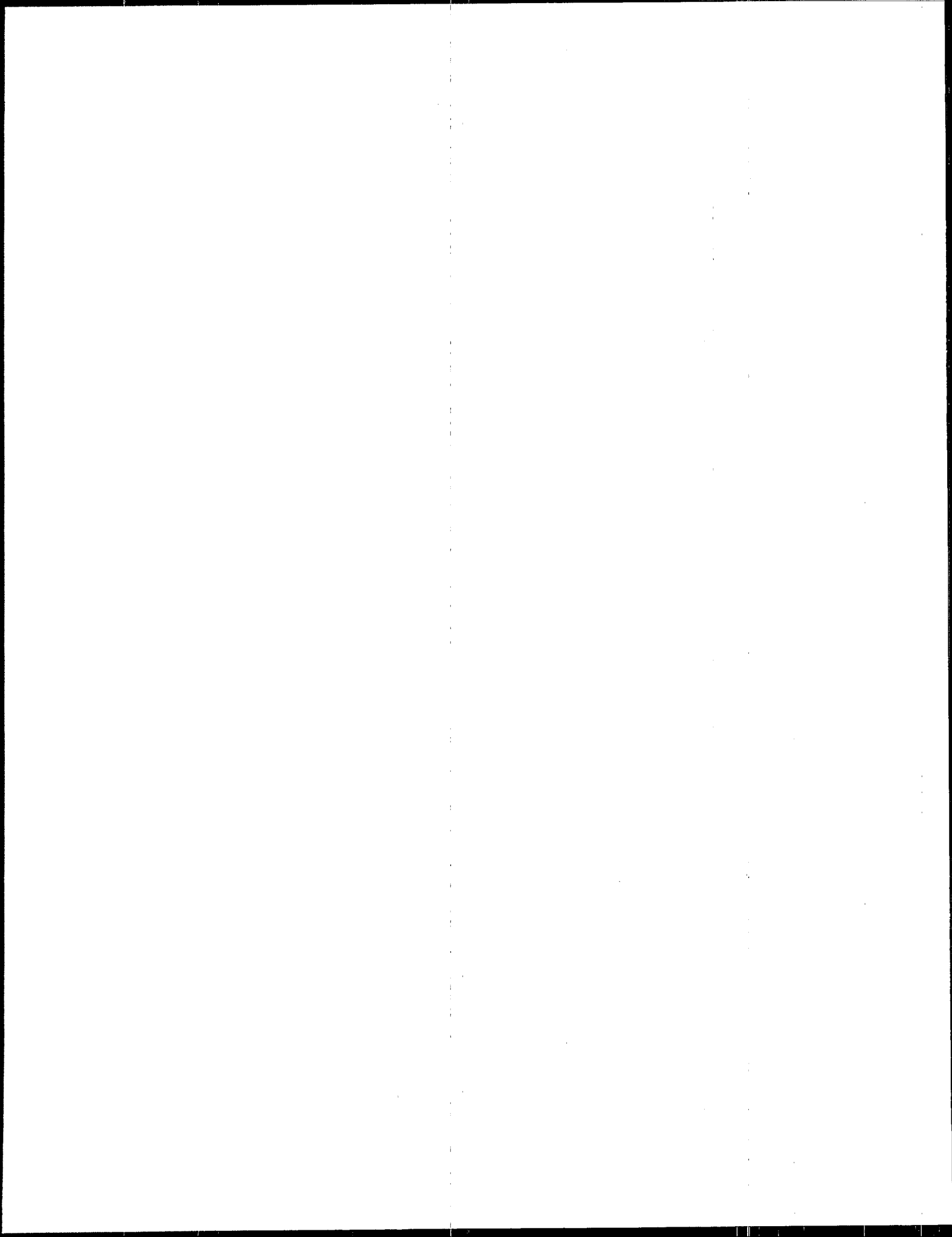
Shape modification strategies involve lagoon design and construction to reduce the ultimate rate of volatile emissions. Adjusting berm height achieves this effect by reducing wind-caused emissions. Increasing the ratio of depth-to-surface area also produces reduced emissions. Orienting the lagoon with its long axis perpendicular to prevailing winds helps reduce emissions by maximizing the surface area which benefits from proximity to shoreline protection.

Aerodynamic Modification

Aerodynamic modification through the use of wind fences represents another strategy for reducing emissions under wind-enhanced conditions. Porous wind fence material (such as that used for dust control) is superior to solid fences. This material can achieve emission and oxygen absorption reductions of up to 80 percent. The wind fence can be aligned to protect from several wind directions and can be used to complement the effects of lagoon orientation and floating covers. Reduction of wind velocity can be expected for a distance of 1 to 5 fence heights downwind of the installation. Fences should be composed of polyester or other high-strength materials to ensure their resistance to wind damage (University of Arkansas and Louisiana State University, 1985).

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Chapter 4

Engineering Considerations for the Corrective Measures Study

The Corrective Measures Study (CMS) elements as outlined in the EPA document entitled *RCRA Corrective Action Plan - Interim Final* (U.S.EPA, 1988) provides guidance to the regulatory community on the steps practiced by the engineering community in the conduct of a feasibility study. These steps include:

- Identification and development of Corrective Measure Alternatives
- Evaluation of Alternatives
- Selection of a Corrective Measure(s) for Implementation.

This logical process ensures that all appropriate technologies are identified and evaluated on an equal basis.

Identification and Development of Corrective Measures Alternative(s)

In order to begin the process of identification and development of Corrective Measure Alternatives, it is necessary first to define the problem in terms of the site conditions determined as a result of the RCRA Facility Investigation (RFI). Then, site-specific objectives for the corrective action need to be established to serve as a basis for technology assessment and to establish the end point for cleanup activities. These objectives are generally based on public health and environmental criteria, information gathered during the RFI, EPA guidance, and the requirements of any applicable Federal or state statutes. For example, all corrective actions concerning groundwater releases from regulated units must be consistent with, and as stringent as, those required under 40CFR264.100. With information on current site conditions and with cleanup objectives defined, it becomes possible to develop corrective measure alternatives by screening the possible technologies and combinations of technologies identified early in the RFI.

Screening of Corrective Measures Technologies

The first step in the screening process is to review the results of the RFI and reassess the preliminary corrective measure technologies identified therein along with any supplemental technologies which have come to light. By compiling a listing of all possible treatment alternatives suitable for the site, an engineer can then eliminate (1) those that may prove infeasible to implement, (2) those that rely on technologies unlikely to perform satisfactorily or reliably, or (3) those that do not achieve the corrective measure objective within a reasonable time period. From an engineering standpoint, the screening process focuses on eliminating those technologies which have severe limitations for a given set of wastes and site-specific conditions. The screening step may also eliminate technologies based on inherent technology limitations. Site, waste and technology characteristics which are used to screen inapplicable technologies are described in more detail below.

Site Characteristics

Site data should be reviewed to identify conditions that may limit or promote the use of certain technologies. Technologies whose use is clearly precluded by site characteristics should be eliminated from further consideration.

Waste Characteristics

Identification of waste characteristics that limit the effectiveness or feasibility of technologies is an important part of the screening process. Technologies clearly limited by these waste characteristics should be eliminated from consideration. Waste characteristics particularly affect the feasibility of on-site methods, direct treatment methods, and land disposal (on/off-site).

Technology Limitations

During the screening process, the level of technology development; performance record; and inherent construction, operation, and maintenance problems

should be identified for each technology considered. Technologies that are unreliable, perform poorly, or are not fully demonstrated may be eliminated in the screening process. By contrast, certain treatment methods have been developed to a point where they can be implemented in the field without extensive technology transfer or development.

Through a stepwise approach to the screening of alternatives, the engineer can gain confidence that technologies which may be applicable for site cleanup are not overlooked. In addition, the rationale for the elimination of specific technologies is available to justify these engineering decisions to management, or the regulatory community, and the public.

Identification of the Corrective Measure Alternative(s)

Based on the screening activities, several alternatives may be identified which are viable options for the cleanup of the site. These alternatives can consist of an individual technology or a combination of technologies which appear to be appropriate for the given site conditions and appear to be capable of meeting the cleanup objectives.

Evaluation of the Corrective Measure Alternative(s)

Once the candidate corrective measure alternatives have been identified, a more detailed evaluation of each alternative needs to be undertaken. From an engineering perspective, the first step in the evaluation process would include the development of a conceptual design for each alternative. The conceptual design would consist of a process description, a process flow diagram and a layout drawing. Preliminary sizing of equipment and utility and land requirements would be developed. In addition, chemical requirements and residuals produced can be estimated. From the conceptual design, permitability and residuals disposal issues can be identified and addressed.

Evaluation Criteria

After the conceptual designs for each candidate corrective measure alternative have been developed, each can be compared using the following evaluation criteria:

Technical Criteria

- Performance of the corrective measure based on the effectiveness of the technology to perform its intended function and the length of time the level of effectiveness can be maintained.
- Reliability of the corrective measure based on operating and maintenance requirements and

the demonstrated reliability. (This criterion is concerned with the complexity of a system and its impact on operation, maintenance and potential for failure.)

- Implementability of the corrective measure is concerned with the constructability of the facilities (i.e., site constraints, permitability, equipment availability, and the time it takes to implement and to operate and maintain the facility.)
- Safety issues include threats to the safety of workers or nearby communities during the implementation or operation of the corrective measures (i.e., fire, explosion and exposure to hazardous substances).

Environmental Criteria

An Environmental Assessment for each alternative (focusing on the facility conditions and pathways of contamination actually addressed by each alternative) should be prepared. Issues to be reviewed include: the short- and long-term beneficial and adverse effects of the response alternative; any adverse effects on environmentally sensitive areas; and an analysis of measures to mitigate adverse effects.

Human Health Criteria

Each alternative should be assessed in terms of the extent to which it mitigates short- and long-term potential exposure to any residual contamination and protects human health, both during and after implementation of the corrective measure.

Institutional Criteria

Institutional needs for each alternative must be developed as part of the technology evaluation. Specifically, this should address the effects of federal, state and local environmental and public health standards, regulations, guidance, advisories, ordinance or community relations on the design, operation and timing of each alternative.

Cost Estimate

An estimate of the cost for each corrective measure alternative should be developed, including capital, operating and maintenance costs. Capital costs consist of direct (construction) and indirect (nonconstruction and overhead) costs.

- Direct capital costs include:
 - Construction costs

- Equipment costs
- Land and site-development costs
- Buildings and service costs
- Indirect capital costs generally include:
 - Engineering expenses
 - Legal fees and license or permit costs
 - Start-up and shake-down costs
 - Contingency allowances

Operation and maintenance costs are post-construction costs necessary to ensure continued effectiveness of a corrective measure. The following are examples of typical operation and maintenance costs:

- Operating labor costs
- Maintenance materials and labor costs
- Auxiliary materials and energy

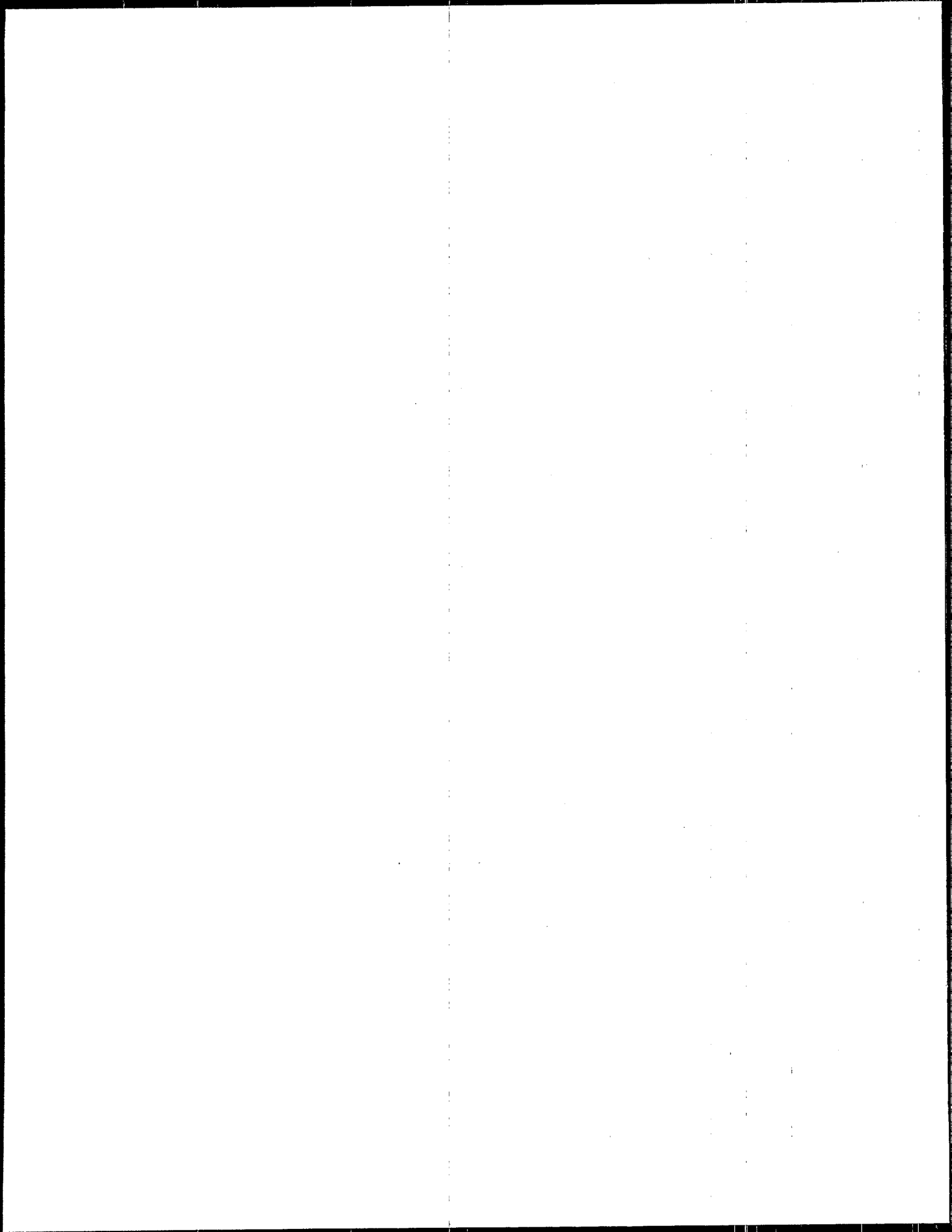
- Purchased services
- Disposal and treatment costs
- Administrative costs
- Insurance, taxes and licensing costs

Justification and Recommendation of the Corrective Measure(s)

After each issue outlined in the evaluation criteria has been developed for each corrective measure, the selection of the most appropriate alternative can be made. Trade-offs among health risks, environmental effects and other pertinent technical, environmental and human health factors enter into this decision-making process. In the RCRA context, cost is not a factor in the selection process except when two or more corrective measure alternatives are determined by EPA to provide similarly adequate levels of protection of human health and the environment.

References

U. S. EPA. *RCRA Corrective Action Plan - Interim Final*, EPA/530-SW-88-028, Office of Solid Waste and Emergency Response, Washington, D.C., 1988.



Chapter 5

Technology Options for the Treatment of Wastes and Waste Streams

In nearly every phase of the Corrective Action process, some information about treatment technologies is needed - e.g., in the pre-investigation planning for data gathering, in the screening and evaluation of candidate remediations, in lab and pilot studies, and in design, implementation, operation and monitoring of the selected remedy. Many documents exist which describe candidate technologies in detail and give their respective applicability and limitations. One intent of the seminar on which the present document is based is to present a broader perspective on several types of remedial technologies, their applicability and limits from a CA perspective and an understanding of how process residuals may themselves require additional treatment to achieve protection of human health and the environment (HHE).

Chemical Treatment Processes for Corrective Action

What Is Chemical Treatment?

Chemical treatment is a class of processes in which specific chemicals are added to wastes or to contaminated media in order to achieve detoxification. Depending on the nature of the contaminants, the chemical processes required will include pH adjustment, lysis, oxidation, reduction or a combination of these. Thus, chemical treatment is used to effect a chemical transformation of the waste to an innocuous or less toxic form. In addition, chemical treatment is often used to prepare for or facilitate the treatment of wastes by other technologies. Figure 12 identifies specific treatment processes which perform these functions.

To understand chemical treatment processes, it must be remembered that a reaction is not a process. A reaction involves the chemical transformation of a material, whether this is carried out on a lab-scale or an industrial-scale. A process, on the other hand, is a series of actions or operations needed to make such a reaction occur in a controlled manner. Thus, the development of a process requires the design of the

equipment, the process controls, and the ancillaries necessary to make the reaction proceed in a full-scale facility. Figure 13 represents a flow diagram of a generic chemical treatment process showing the inputs and outputs which require consideration.

Before the selection of a specific treatment technology can be made, an understanding of the site-specific factors which drive the selection of that technology is required because these factors can influence the evaluation of the advantages and limitations of competing technologies. The information required to resolve these site-specific issues falls into four categories: waste composition and matrices, waste quantity, treatment objectives, and the reactions involved in the treatment of the contaminated material.

Applicability Based On Waste Type

In general, chemical treatment processes are applicable to a broad range of organic and inorganic wastes. For example, they can be used for the oxidation of organics, for pH adjustment to precipitate heavy metals, and for lysis of chlorinated organics to cleave chlorine atoms from organic molecules in preparation for subsequent oxidative processes. It should be remembered that chemical processes are very specific as to the waste that they treat. Thus, it is frequently necessary to link several unit operations together to effect the desired removal objectives. Other waste components must also be carefully considered because they can affect the chemical process by consuming more reagents, generating unwanted precipitates, inhibiting the reaction or creating safety issues when their presence is not recognized (e.g., the production of intermediates such as CN^- , S^{2-}).

Applicability Based On Waste Form

Chemical treatment processes rely on the intimate mixing of reagents with the waste. Thus, the wastes generally treated by chemical means must be in an aqueous or slurry form.

Figure 12. Chemical processes.

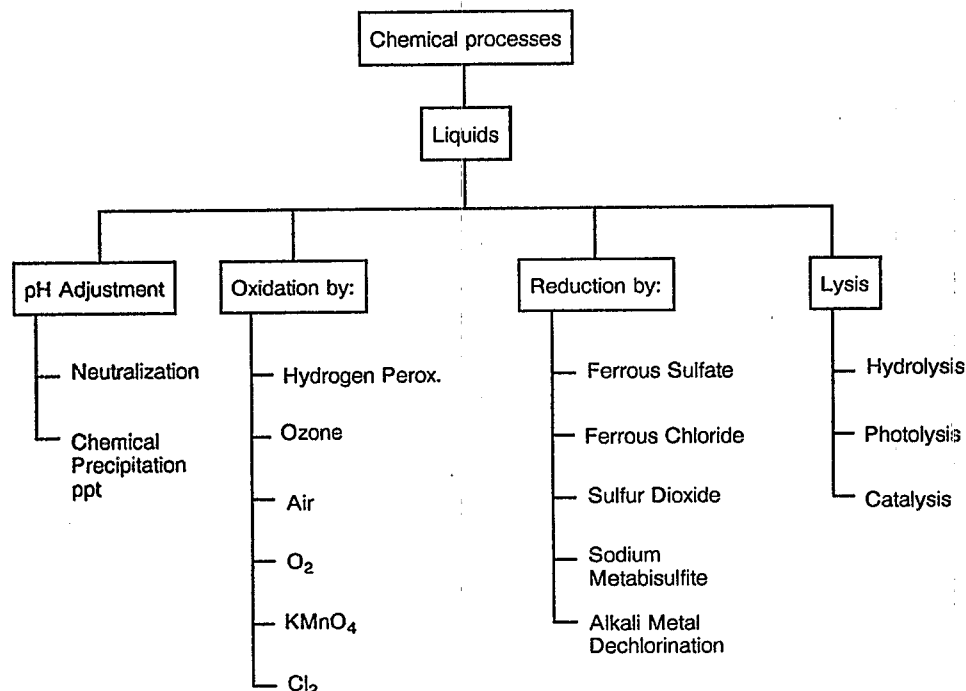
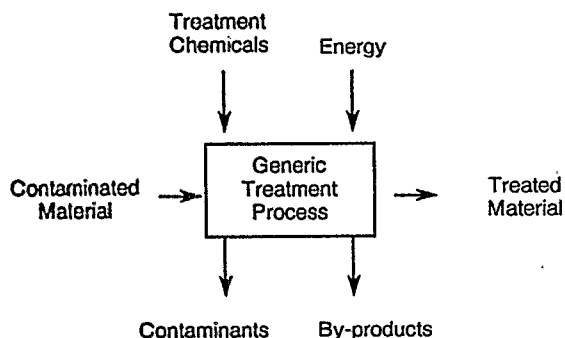


Figure 13. Flow diagram of a generic chemical treatment process.



corrosive wastes. Figure 14 is a general flow schematic which illustrates the pH adjustment process.

pH Adjustment for Neutralization

Technology Description: Neutralization is a process used to treat acids or alkalis (bases) in order to reduce their reactivity or corrosiveness. Neutralization can be an inexpensive treatment if waste alkali can be used to treat waste acid and vice versa. Typical neutralizing reagents include:

Acid: H_2SO_4 , HCl and HNO_3
 Base: $\text{Ca}(\text{OH})_2$, CaO , NaOH , NaHCO_3 ,
 Na_2CO_3 and $\text{Mg}(\text{OH})_2$

Treatment Options and Their Applications

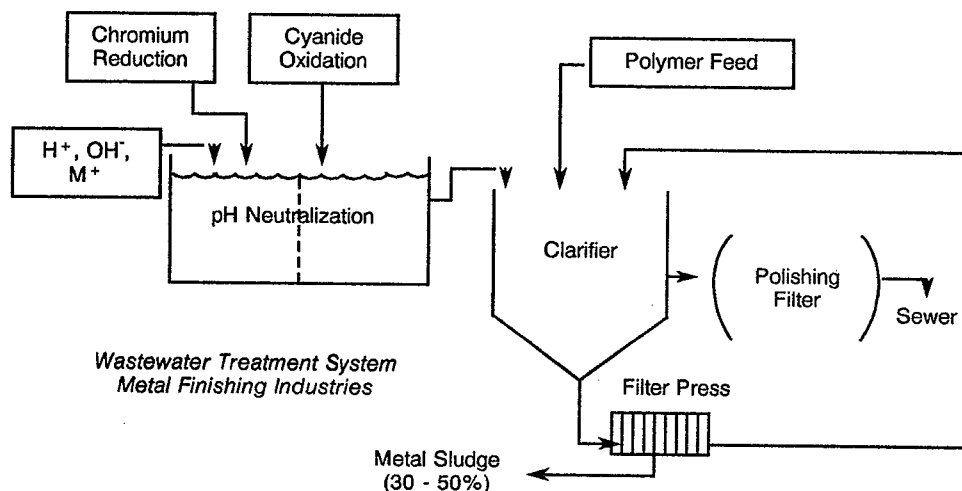
pH Adjustment

The function of pH adjustment is to neutralize acids and bases and to promote the formation of precipitates (especially of heavy metal precipitates) which can subsequently be removed by conventional settling techniques. These purposes are not mutually exclusive, precipitates can be formed as the result of neutralizing a waste. Conversely, neutralization of the waste stream can result when adjusting the pH to effect chemical precipitation. Typically, pH adjustment is effective in treating inorganic or

Applicability: Neutralization would be appropriate for acidic and basic wastes. The process should be performed in a well-mixed system. Care should be taken to ensure compatibility of the waste and treatment chemicals to prevent the formation of more toxic compounds.

Residuals Produced: The resulting effluent may contain dissolved inorganic salts at concentrations which may be unacceptable for discharge. Based on the chemical composition of the waste stream, a precipitate may be formed which may require removal and disposal.

Figure 14. pH adjustment system.



Corrective Action Application: An acidic groundwater at a Florida site (pH 2.5-3) required treatment. The groundwater was collected by extraction wells, pumped to an above-ground reactor, and neutralized with lime. In the course of neutralizing the waste stream, precipitates were formed which were removed by clarification and filtration prior to discharge. Sludges produced from the clarification and filtration steps were dewatered by a filter press.

pH Adjustment to Effect Chemical Precipitation

Technology Description: To achieve precipitation, acid or base is added to a solution to adjust the pH to a point where the constituents to be removed have their lowest solubility. Chemical precipitation facilitates the removal of dissolved metals from aqueous wastes. Metals may be precipitated from solutions as hydroxides, sulfides, carbonates, or other soluble salts. A comparison of precipitation reagents is presented in Table 7. Solid separation is effected by standard flocculation/coagulation techniques.

Table 7. Comparison of Precipitation Reagents

Lime	least expensive, generates highest sludge volume
Caustic and Carbonates	more expensive than lime, generates smaller amount of sludge, applicable for metals where their minimum solubility within a pH range is not sufficient to meet clean-up criteria
Sulfides	effective treatment for solutions with lower metal concentrations
Sodium borohydride	expensive reagent, produces small sludge volumes which can be reclaimed

Applicability/Limitation: This technology is applicable for aqueous wastes containing heavy

metals (i.e., Cd, Cr (III), Pb, Ni). The optimum pH for minimum solubility of various metals is not the same, therefore, solutions containing mixed metals introduce a limitation to the system. Figure 15 graphically shows the solubility of metal hydroxides as a function of pH. Chelating or complexing agents present in the waste stream may inhibit the formation of a desired precipitate.

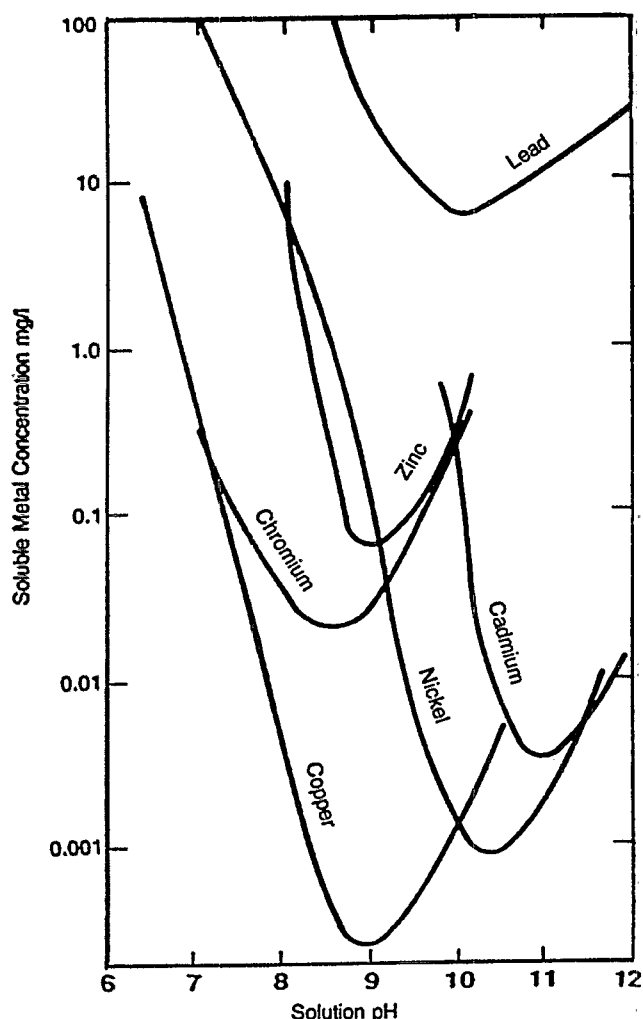
Residuals Produced: Resulting metal sludges from the chemical precipitation process may require further treatment prior to disposal. The effluent pH may require an adjustment before it may be discharged. Dissolved inorganics present in the effluent may pose a problem for direct discharge.

Corrective Action Application: Gulf Coast Lead is a small, secondary lead smelting facility in Florida, which recovers lead from discarded lead acid batteries and lead from other battery breakers. Contaminated rinsewater and battery casings were dumped into an unlined surface depression causing the soil and the shallow groundwater to become heavily contaminated with sulfuric acid and heavy metals. A groundwater treatment and recovery system was installed consisting of primary clarification followed by pH adjustment (using lime or caustic soda) and final clarification. The system reduced lead concentrations from 6 ppm to below 0.3 ppm and adjusted the pH from 1.5 to 9.7. The cleanup objectives required that the effluent be below 0.3 ppm lead and the discharge volume from the treatment system be 20,000 gpd.

Oxidation and Reduction Processes

Oxidation and reduction must both take place in any such reaction. In any oxidation reaction, the oxidation state of one compound is raised (i.e., oxidized) while the oxidation state of another

Figure 15. Solubilities of metal hydroxides as a function of pH.



compound is lowered (i.e., reduced). Oxidation and reduction reactions are utilized to change the chemical form of a hazardous material in order to render it less toxic or to change its solubility, stability, separability or otherwise change it for handling or disposal purposes. In the reaction, the compound supplying the oxygen (or chlorine or other negative ion) is called the oxidizer or oxidizing agent while the compound accepting the oxygen (i.e., supplying the positive ion) is called the reducing agent. The reaction can be enhanced by catalysis, electrolysis or photolysis.

Chemical Oxidation

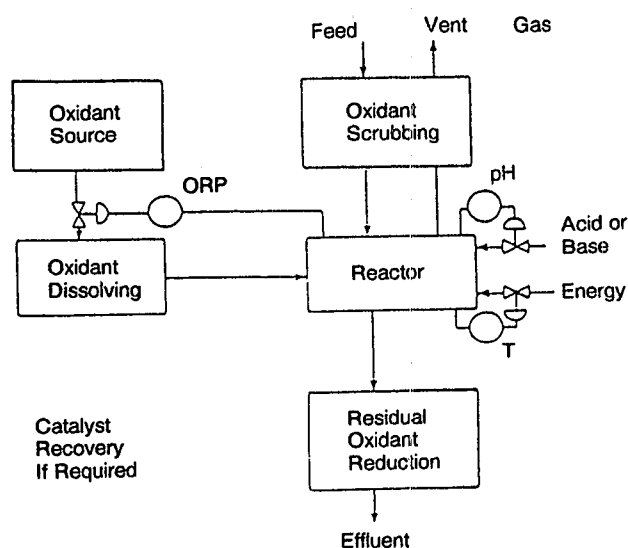
Technology Description: Oxidation processes involve the conversion of organics to CO_2 , H_2O , HCl , NO_2 and SO_3 or the conversion of inorganics to a more desirable form. For both organic and inorganic wastes, the function of chemical oxidation is to

change the chemical form of the molecular structure for the purpose of detoxification. Typical oxidants used for oxidation processes are:

Air	Cl_2
O_2	ClO_2
H_2O_2	KMnO_4
O_3	NaS_2O_7

Oxidation processes may rely on pH adjustment to enhance the chemical reaction. Figure 16 illustrates the typical configuration of a chemical oxidation process. The major engineering considerations for chemical oxidation include: reaction kinetics, mass transfer, by-products, temperature, oxidant concentration, pH and vent gas scrubbing.

Figure 16. General process flowsheet for chemical oxidation.



Applicability/Limitations: The process is nonspecific. Solids must be in solution. Reactions can be explosive. Waste composition must be well known to prevent the inadvertent production of a more toxic or more hazardous end product. Oxidation processes are applicable for the following classes of organic contaminants:

- High reactivity contaminants: phenols, aldehydes, aromatics, amines, some sulfur compounds.
- Medium reactivity contaminants: alcohols, ketones, organic acids, esters, alkyl-substituted aromatics, nitro-substituted aromatics, carbohydrates.
- Low reactivity contaminants: halogenated hydrocarbons, saturated aliphatics, benzene.
- Cyanide-bearing wastes.

The reaction mechanism depends on the chemistry of the active oxidant and chemical contaminants. Multiple sequential and parallel reaction steps occur frequently. Partial oxidation produces noxious by-products.

Residuals Produced: Typical residuals resulting from oxidation are partial oxidation products (e.g., chlorinated organics) and inorganic salts (e.g., NaCl, MnO₂). Additional treatment may be required to permit disposal.

Corrective Action Application: At a hazardous waste treatment storage and disposal facility in Washington State, a cyanide-bearing waste required treatment. The influent waste stream contained 15 percent cyanide. Electrolytic oxidation was used to reduce the cyanide concentration to less than 5 percent. Alkaline chlorination was used to further reduce the cyanide concentration to 50 mg/l (the cleanup objective). The electrolytic process was used as a first stage treatment because the heat of reaction, using alkaline chlorination to treat the concentrated cyanide waste, would be so great that it would melt the reactor tank.

Chemical Reduction

Technology Description: The function of reduction processes is to convert inorganics to a less toxic and/or more easily treated form. It also serves as a pretreatment step for inorganics in which chemical precipitation is used to remove the metal hydroxide from solution.

Applicability/Limitations: Reduction processes are applicable for:

- Hexavalent chromium waste
- Mercury wastes
- Hexavalent selenium
- Organic lead compounds
- Chelated-metal-bearing wastes

Chemical reduction process limitations include the following:

- Reducing agents are non-selective.
- Violent reactions are possible.
- Air emissions and odors can be produced.
- Slurries, tars or sludges are difficult to treat.

Residuals Produced: The reaction products are usually inorganic salts.

Corrective Action Application: At a RCRA site in the southwest, a waste stream containing hexavalent chromium was reduced to the trivalent form. The trivalent chromium was then removed using ion exchange. The influent hexavalent chromium

concentration was less than 50 ppm, and the effluent concentration was 0.5 mg/l (the cleanup objective).

Alkali Metal Dechlorination

Technology Description: Chlorinated organics represent a large class of toxic and hazardous substances that are difficult to treat. The purpose of this process is to displace the chlorine from the chlorinated compound. By-products include chloride salts, which can be removed by centrifugation and filtration. The reagents used are metallic sodium and potassium in conjunction with proprietary reagents. For the sodium based processes, the reagents are suitable for treating oils containing less than 1000 ppm PCBs.

Applicability/Limitations: Alkali metal dechlorination is applicable to chlorinated hydrocarbons such as:

- PCBs (e.g., transformer decontamination)
- Dioxins
- Solvents
- Pesticides

Alkali metal dechlorination processes are water sensitive. Soil moisture content can adversely affect the reaction in in-situ soil applications. The application of alkali metal dechlorination is generally expensive.

Residuals Produced: The residual produced from the alkali metal dechlorination of soils is reported to be an alkaline soil which requires neutralization.

Corrective Action Application: At a Navy facility in Guam, approximately 25 tons of PCB contaminated soil was treated using the KPEG (potassium polyethylene glycol) process. PCB concentrations were reduced from 3000 ppm to less than 5 ppm. Upon completion of treatment using the KPEG process, the soil was neutralized from a pH of 14 to 7. A full-scale system for this process is currently under development.

Lysis Processes

The basic function of lysis processes is to split molecules to permit further treatment. Hydrolysis is a chemical reaction in which water reacts with another substance. In the reaction, the water molecule is ionized while the other compound is split into ionic groups. Photolysis, another lysis process, breaks chemical bonds by irradiating a chemical with ultraviolet light. Catalysis uses a catalyst to achieve bond cleavage.

Hydrolysis

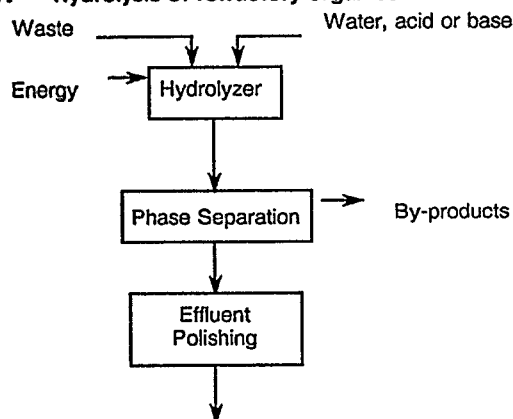
Technology Description: Hydrolysis is the process of breaking a bond in a molecule (which is ordinarily not water-soluble) so that it will go into ionic solution with water. Hydrolysis can be achieved by the addition of chemicals (e.g., acid hydrolysis), by irradiation (e.g., photolysis) or by biological action (e.g., enzymatic bond cleavage). The cloven molecule can then be further treated by other means to reduce toxicity.

Applicability/Limitations: Hydrolysis is suitable for pretreating difficult-to-treat wastes and for organics with substituents, such as phenols or chlorinated organics with reactive chlorine atoms. Hydrolysis is specific for only a limited number of contaminants.

Residuals Produced: The resulting residuals from a hydrolysis process are an aqueous effluent and insoluble organics.

Corrective Action Application: Hydrolysis was favorably applied to a site in which the wastewater contained very soluble, refractory organics. In addition, tars were being produced in high quantities on this site. Both of these problems were solved using a hydrolyzer. Figure 17 illustrates a flow diagram of this process. As a result, the wastewater treatment goals were achieved, and the production of tar was reduced.

Figure 17. Hydrolysis of refractory organics.



Ultraviolet Photolysis

Technology Description: Ultraviolet (UV) photolysis is a process that destroys or detoxifies hazardous chemicals in aqueous solutions utilizing UV irradiation. Absorption of UV energy results in a molecule's cleavage, increasing the ease of subsequent oxidation of the molecule. For example, ultraviolet light has been used for degradation of dioxins in waste sludge. This process required extraction (into a clean, transparent solvent) of the waste to be destroyed. Reaction products were

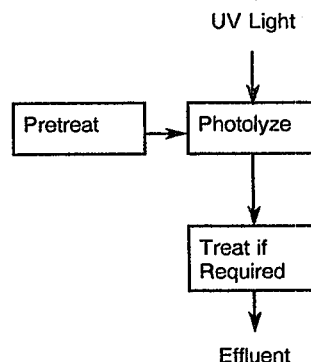
dechlorinated materials and free chlorine gas. In addition, the use of UV photolysis on nitrated wastes has been successfully demonstrated on a pilot scale.

Applicability/Limitations: Photolysis is appropriate for difficult-to-treat chemicals (e.g., pesticides, dioxins, chlorinated organics), nitrated wastes, and those chemicals in media which permits photolyzing the waste. The waste matrix can often shield chemicals from the light (e.g., ultraviolet light absorbers, suspended solids, solid wastes). The photolysis process typically requires pretreatment to remove suspended materials, and the by-products formed may be more toxic than the parent molecules.

Residuals Produced: Photolysis produces decomposition products of dechlorinated material and free chlorine gas.

Corrective Action Application: At a manufacturing site, photolysis was used to cleave chlorine atoms from tetrachlorodibenzodioxin (TCDD). The basic flow diagram for the process is shown in Figure 18. The wastes from a hexachlorophene process were stored in an underground tank which held 4300 gallons of the oily residuals containing 343 ppm TCDD. This material required removal and treatment. The selected treatment system consisted of a batch solvent extractor to transfer the TCDD into a cleaner fluid more amenable to photolysis. The solvent was separated from the oil, circulated through a bank of eight 10-kW ultraviolet lights, recovered and recycled. Effluent from this process contained 0.15 ppm TCDD.

Figure 18. Photolysis flow diagram.



In-Situ Chemical Treatment

Technology Description: In-situ chemical treatment uses the same principles employed for above-ground chemical processes. Materials are added to neutralize, oxidize or remove contaminants in groundwater or soils in order to avoid digging or pumping of the contaminated waste above ground for

treatment. The reagents which have been used for in-situ chemical treatment include:

- Dilute acids or bases
- Hydrogen peroxide
- Water
- Water with additives
- Air

Applicability/Limitations: In-situ treatment can be used when it is uneconomical to haul or when infeasible or uneconomical to dig or pump the contaminated waste matrix for treatment in a reactor. This approach should be used whenever excavation or removal causes an increased threat to human health. It can reduce the cost of a remediation program. Because chemicals are applied to the contaminated waste matrix, specifically soil and groundwater, a potential exists for reaction with the soil. Permeability problems can occur as the result of precipitate formation. This can result in inadequate mixing of the contaminant with the treatment chemical. Gas generation may also occur.

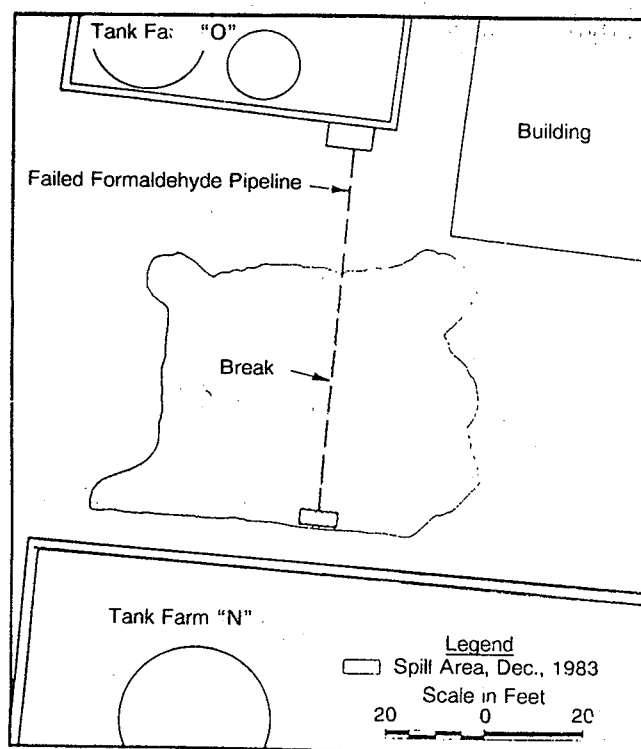
Corrective Action Application: A case involving the cleanup of a 20,000 gallon formaldehyde release utilized in-situ treatment due to the location of the spill. The release occurred from a break in an underground pipeline at a tank farm (Figure 19). The soil could not be excavated because it served as a road for trucks. The objectives were to remediate the release; reduce the long-term liability for oxidizing the formaldehyde; and reduce the time and cost for groundwater treatment without interfering with operations in the area. The process (Figure 20) involved slowly injecting alkaline hydrogen peroxide into the clay till to oxidize the formaldehyde without creating excessive temperature and pressure increases. The results were that the formaldehyde was reduced from percent concentrations to 1-18 ppm. The permeability of the soil improved, and the overall treatment costs were significantly less than removal followed by above-ground treatment.

Biological Processes for Corrective Action

What is Biological Treatment?

Biological treatment is a destruction process relying primarily on oxidative or reductive mechanisms. Enzymatic activity can effect lysis (e.g., hydrolysis or dehalogenation). Further, biological activity can result in pH changes in the waste stream which may require adjustment by chemical means. The use of biological treatment processes is directed toward accomplishing (1) destruction of organic contaminants, (2) oxidation of organic chemicals whereby the organic chemicals are broken down into smaller constituents, and (3) dehalogenation of

Figure 19. Site of formaldehyde release.



organic chemicals by cleaving a chlorine atom(s) or other halogens from a compound. Specific engineered systems to effect oxidation and reduction for different matrices are presented in Figure 21. Biological treatment processes have certain advantages over other common treatment technologies, namely, the organic contaminants to be destroyed are used and transformed by bacteria or other organisms as a source of food. These processes can be employed in soils, slurries, or waters (ponds, groundwater, etc.) to aid in the remediation of a site.

Applicability Based on Waste Type

Biological processes can be used on a broad class of biodegradable organic contaminants. Table 8 presents some common RCRA-regulated organic compounds which are susceptible to biodegradation. Some compounds, called refractiles, are persistent compounds which are not readily biodegradable. It should be noted that very high concentrations as well as very low concentrations of organic contaminants are difficult for biological processes to treat.

Applicability Based on Waste Form

Biological treatment processes can be used to treat organic contaminants in liquid, slurry, and soil matrices. However, it should be remembered that moisture is an essential need of the biomass both for

Figure 20. Diagram of *in-situ* treatment.

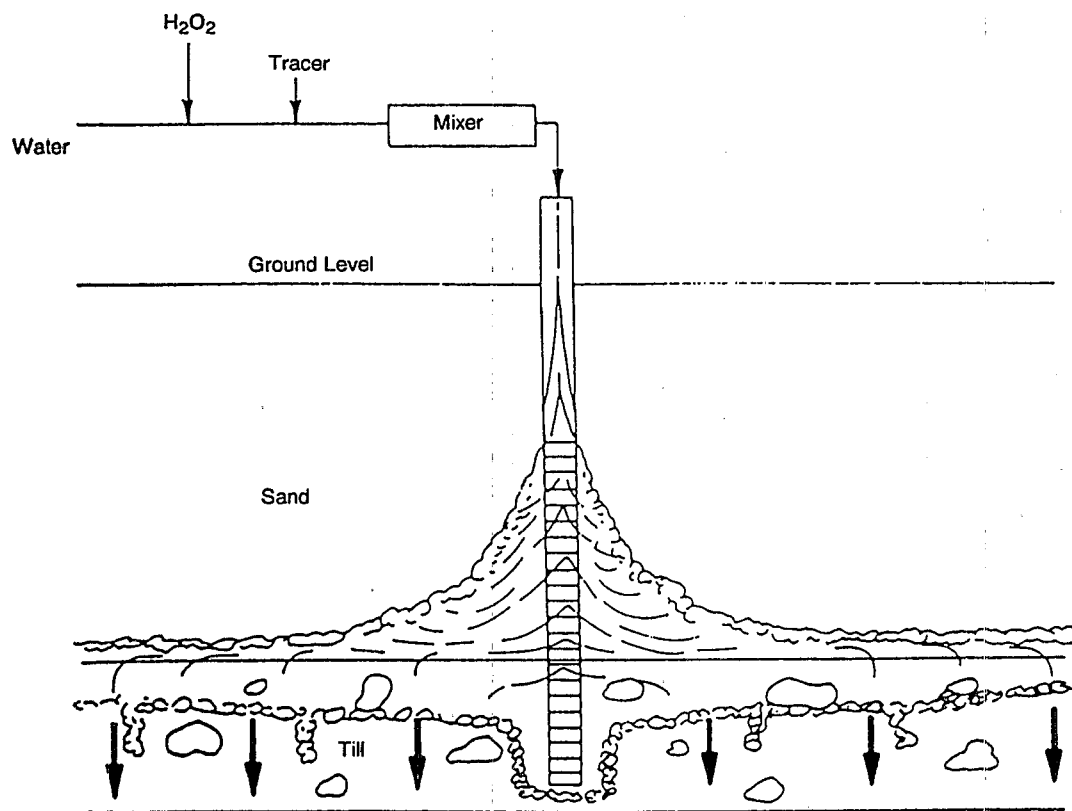
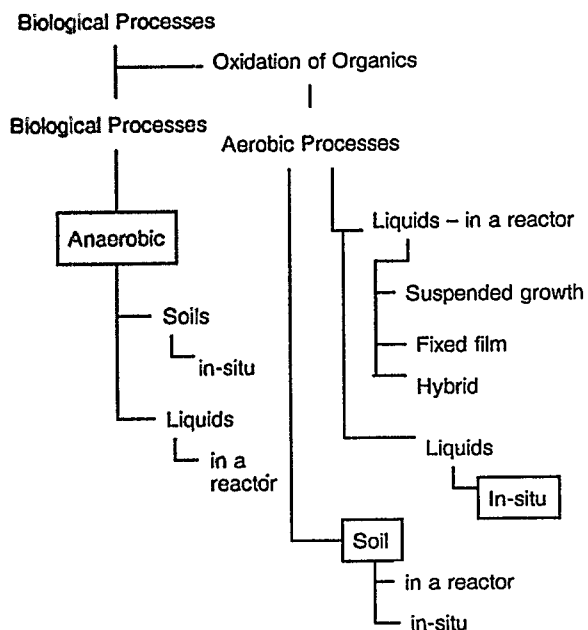


Figure 21. Biological processes.



growth and to provide mobility either of the food to the biomass or the biomass to the organic. Thus, matrices which do not have sufficient moisture will not support biodegradation, and methods to add moisture may have to be engineered into the system.

Environmental Factors Necessary to Maintain the Biomass

Since microorganisms need appropriate conditions in which to function, an engineer must provide an optimum environment, whether above ground in a reactor or below ground for an *in-situ* application. The primary environmental factors which can affect the growth of the microbial community - in addition to providing them with sufficient food (organic material) - are pH, temperature, oxygen concentration, nutrients, and toxicity.

pH

Typically, the biological treatment system operates best when a waste stream is at a pH near 7. However, waste treatment systems can operate (with some exceptions) between pH values of 4 and 10. The

exceptions are aerobic systems in which ammonia is oxidized to NO_x as well as anaerobic methane fermentation systems. For these, the pH should be between 6 and 8. At the extremes of this range, the system will function, but efficiency will suffer.

Temperature

Waste treatment systems can function over a very wide temperature range, e.g., 5° to 60°C. However, there are three rather distinct ranges in which different groups of organisms function:

Psychrophilic	< 15°C
Mesophilic	15° to 45°C
Thermophilic	> 45°C

Most waste treatment systems operate in the mesophilic region. The expense of altering the temperature of wastes encountered in abnormally cold or warm environments indicates the desirability of developing organisms which are suited to extremes of ambient waste temperatures.

Oxygen

Microorganisms need a certain amount of oxygen not only to survive, but also to mediate their reactions. Therefore, the residual dissolved oxygen concentrations should be maintained at approximately 2 mg/l or greater within a typical liquid biotreatment system. Having this much oxygen "left over" indicates that sufficient oxygen was available for the biological process.

Nutrients

Nutrients can be classified into three groups based on levels required in waste treatment systems. These are given in Table 9. The major nutrients can be identified from the generalized biomass formula ($\text{C}_{60}\text{H}_{82}\text{O}_{23}\text{N}_{12}\text{P}$). The actual quantity needed depends on the biochemical oxygen demand (BOD) of the waste. The higher the BOD the greater the quantity of cells produced. The minor and trace nutrients are needed in small quantities and are given in terms of concentration because these are the levels needed in solution to force the small amount required inside the cell across the cell-wall membrane.

For many of the trace nutrients, it will be difficult to find literature references to the concentrations required. It is only recently that it has been realized that these trace nutrients are required, because they were only present as contaminants in biological preparations. Indeed, many other substances may be required nutrients but at such low levels that their requirement is not easily manifest.

Toxicity

The presence of toxic substances will obviously produce adverse conditions in a biological system. Unfortunately, it is difficult to cite specific toxic materials because toxicity depends on concentration. All of the nutrients previously mentioned can be toxic if their concentration is excessive. All types of organic compounds which can be used as food by bacteria can be toxic if the level is high enough. Thus, our concept of a toxic substance is a substance which is toxic at a very low concentration. (Little detailed information on ranges in which substances are toxic is available.) In addition, phenomena such as acclimation, antagonism and synergism will alter toxicity effects. Frequently, toxicity concerns can be avoided by waste dilution and by microbe acclimation. Acclimation is most important when dealing with "toxic waste". For example, with unacclimated biomass, a few milligrams per liter of phenol can produce toxicity; but after acclimation, waste treatment systems can easily handle wastes containing up to 500 mg/l of phenol.

Biological Processes and Their Applications

Engineered Processes to Achieve Oxidation

Aerobic processes are oxidative processes and are the most widely used biological treatment processes for organic wastes. These processes rely on providing the basic environmental conditions required for biological growth but use differing methods for maintaining the microorganisms in the system and contacting the organic material with the biomass. Since these systems require a supply of molecular oxygen, the cost of supplying oxygen frequently sets an economic limit on the concentration of organics which can be present in the wastewater. For conventional systems, a limit of approximately 10,000 mg/l BOD is a good rule of thumb. For situations where the flow is low, however, higher concentrations can be economically biodegraded. Engineered aerobic processes include suspended growth systems, fixed-film systems, hybrid reactors and in-situ application.

Suspended Growth Systems

Technology Description: Suspended growth systems maintain the biomass suspended in the aqueous waste to be treated. Intimate mixing brings the food and the microorganisms into contact and permits biodegradation to occur. The biomass is captured as it is washed out of the reactor. Typically, a clarifier is used to capture washout. The biomass is concentrated as sludge and a portion is recycled back to the reactor to maintain the concentration of biomass in the reactor while the remainder is dewatered and disposed. This system allows a long contact time between the organic waste and the biomass. Figure

Table 8. Biodegradable RCRA-Regulated Organic Compounds, (USEPA, 1985)

Substrate Compounds	Respiration		Fermentation	Oxidation	Co-oxidation
	Aerobic	Anaerobic			
Straight Chain Alkanes	+	+	+	+	+
Branched Alkanes	+	+	+	+	+
Saturated Alkyl Halides		+		+	+
Unsaturated Alkyl Halides		+		+	
Esters, Glycols, Epoxides	+	+	+	+	
Alcohols	+	+		+	
Aldehydes, Ketones	+	+		+	
Carboxylic Acids	+	+		+	
Amides	+	+			
Esters	+	+			
Nitriles	+	+			
Amines	+	+			
Phthalate Esters	+	+		+	
Nitrosamines		+			
Thiols					
Cyclic Alkanes	+		+	+	+
Unhalogenated Aromatics	+	+		+	
Halogenated Aromatics	+	+		+	+
Simple Aromatic Nitro Compounds	+	+			
Aromatic Nitro Compounds with Other Functional Groups	+	+			+
Phenols	+	+	+	+	+
Halogenated Side Chain Aromatics	+		+	+	
Fused Ring Hydroxy Compounds	+				
Nitrophenols		+			
Halophenols	+			+	
Phenols - Dihydrides Polyhydrides	+			+	+
Two & Three Ring Fused Polycyclic Hydrocarbons	+			+	
Biphenyls	+				
Chlorinated Biphenyls	+				
Four Ring Fused Polycyclic Hydrocarbons	+				
Five Ring Fused Polycyclic Hydrocarbons	+				
Fused Polycyclic Hydrocarbons	+				
Organophosphates	+	+			
Pesticides and Herbicides	+	+			

Table 9. Nutrients for Biological Treatment

Major	(Quantity depends on waste strength) carbon, hydrogen, oxygen, nitrogen, phosphorus
Minor	1-100 mg/l sodium, potassium, ammonium, calcium, magnesium, iron, chloride, sulfur
Trace	Less than 1 mg/l manganese, cobalt, nickel, vanadium, boron, copper, zinc, various organics (vitamins), molybdenum

22 represents a general illustration of a suspended growth system.

Applicability/Limitations: Suspended growth systems are applicable to organic wastes with a moderate to high organic load. In addition, these systems are less susceptible to shock and thus are suitable where fluctuations in influent feed are anticipated. Limitations to the use of suspended growth systems are generally associated with lower level concentrations of organics in the feed. In these cases, the maintenance of the biomass within the system is not possible because of the low food to mass ratio. In addition, if the growth rate of a viable biomass population is sufficiently slow, then a more positive means for maintaining the biomass in the system is required.

Residuals Produced: The residuals produced from suspended growth systems are the excess biomass produced as the result of biodegradation. In general, this biomass can be disposed without further treatment. However, site-specific conditions may require stabilization prior to disposal.

Corrective Action Application: Under a Gulf Coast hazardous waste site in Robstown, Texas, a portion of the brine groundwater had become contaminated over the course of several years. The sources of contamination were removed, and the plume was confined to the site boundary. The cleanup of the groundwater was the only remaining (and the most difficult) task to perform. The combined influent water had an average concentration of 15,000 mg/l dissolved solids and 1300 mg/l total organic carbon (TOC) with the main component being 400 mg/l of phenol. For reinjection, the influent had to be treated to background quality (< 18 mg/l TOC). Since the natural groundwater is brine, the dissolved solids were not removed. The optimum pumping rate from the wells was determined to be 23,000 gal/day. At this rate of removal and recharge, the design life of the treatment system was projected at 10 years.

The process selection for the treatment system considered several important and unique problems concerned with the treatment of a brine groundwater. The most critical problem was a decrease in the concentration of organics in the groundwater with time as the treated water was returned to the ground and forced back to the central wells. Before the full-scale system was put into service, a large-scale pilot plant was run to ensure that the assumptions made from the laboratory data were correct. In 1984, the full-scale system (as shown in Figure 23) included the following components: a first stage activated sludge system; a second stage fixed-film biological reactor; a dual media filter; and a carbon adsorption column. Using these components of the full-scale system, groundwater was pumped out of the ground, treated, and then recharged back into the ground (Nyer,

1987). As the concentration of the effluent decreases, the system configuration is modified (Figure 23).

Fixed-Film Systems

Technology Description: Fixed-film reactors rely on maintaining the biomass on some media and passing the contaminated organic material over that media to promote biological activity. In classical municipal treatment, trickling filters are an example of a fixed-film system. In the industrial and hazardous waste treatment arena, fixed-film reactors make use of rotating biological contactors (RBC) or packed media reactors. Oxygen transfer is promoted by (1) in the case of the RBC, rotating the discs into and out of the waste stream, and (2) in the case of packed media reactors, passing a thin liquid layer over the media. The advantages of these processes include the following:

- The biomass is retained in the reactor on inert media.
- The design of the bioreactor is based on the specific surface area.
- High concentrations or high mass of viable bacteria can be maintained in a relatively small volume.
- BOD removal is approximately 85 to 90 percent.

An illustration of a fixed-film reactor system is presented in Figure 24.

Applicability/Limitations: Fixed-film reactors are applicable to influents containing lower concentrations of organics or for maintaining a specialized, slow growing biomass such as would be required to degrade complex organic wastes. A variation of this concept is a kind of in-situ or on-site treatment in which the soil serves as the media and nutrients are passed through the soil to promote bacterial growth. Because the flow through these systems is essentially plug flow, fixed-film reactors are adversely impacted by shock loadings. In addition, high concentrations of organics in the feed can produce excessive amounts of biomass which can clog or (by sheer weight) destroy the media supporting the biomass.

Residuals Produced: The residuals produced in a fixed-film reactor are normally small when compared to the residuals produced in a suspended growth system. There can be some sloughing of biomass during system operations, and this may need to be separated from the effluent. The residuals, depending on site-specific requirements, may require additional treatment prior to ultimate disposal.

Corrective Action Application: At a dry cleaning facility in a desert area of California, an underground solvent storage tank was found to have leaked for many years. The soil from the 100-ft x 160-ft by 20-ft

Figure 22. Diagram of the suspended growth system.

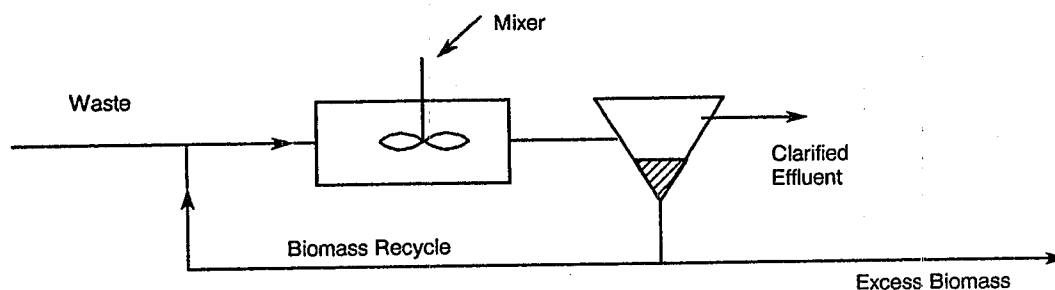
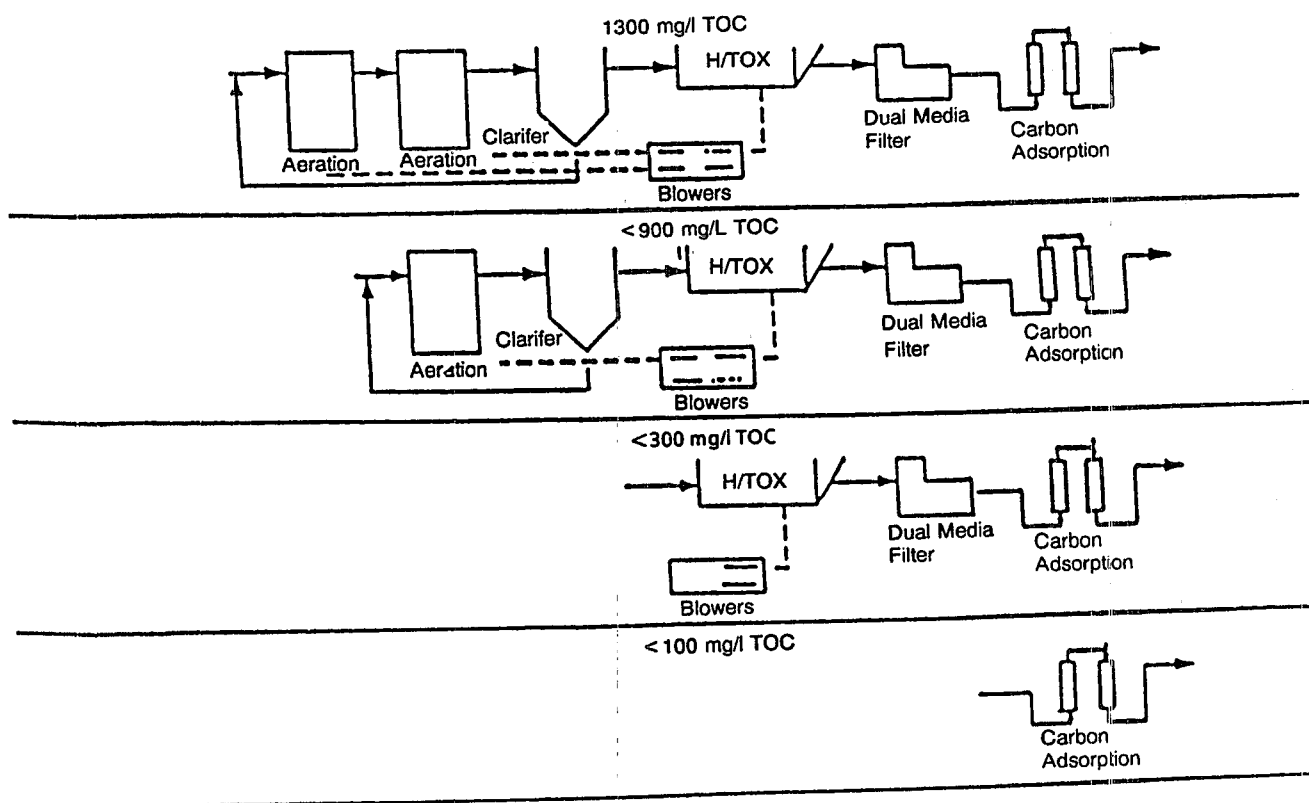


Figure 23. Life-cycle design – installed system at southern Texas site (treating phenol in a brine aquifer) (Nyer, 1987).

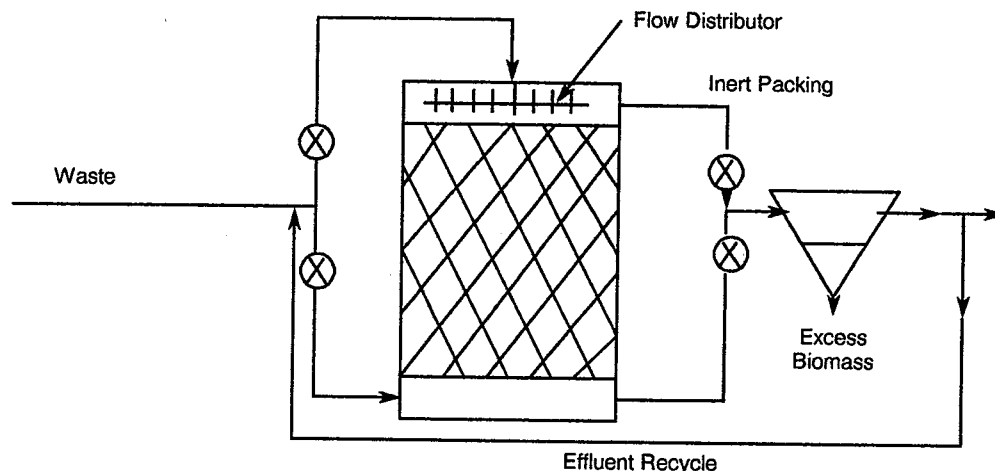


deep site was excavated. The pit was lined with plastic and covered by gravel for drainage. The soil was put back into the lined pit. Nutrient rich water was allowed to percolate down through the soil to feed the indigenous microbes. The water was recovered from a ground drain (C. Russ, EMCON Associates, personal communication, 1988).

Some key issues learned from this case were:

- Injection of acidic, nutrient-rich water into the highly alkaline soils resulted in "cementing" of the soils.
- To alleviate this "cementing", the microbes were grown above-ground in a 500-gal container. They were then allowed to percolate down through the soil. This inoculum had a neutral pH and did not react with the soil.

Figure 24. Diagram of the film flow reactor.



- At a percolation rate of 500 gal/day, the time for cleaning the soil is projected to be 6 months.

Hybrid Reactors

Technology Description: Hybrid reactors, as the name implies, are a combination of suspended growth and fixed-film reactor principles. In these systems, the fixed film is submerged and the reactor contents are continuously stirred. A large amount of biomass is maintained in the system.

Applicability/Limitations: Hybrid reactors, depending upon their configuration, can handle high organic loads (i.e., in the range of 50 to 10,000 ppm). Because these reactors are a completely mixed system, they are less affected by shock loadings. Hybrid reactors are designed to compensate for the principal limitations of fixed-film and suspended growth reactors. However, set-up and operation of hybrid reactors will tend to be somewhat more technically demanding than either fixed-film or suspended growth systems.

Residuals Produced: As with the suspended growth and fixed-film systems, some biomass is produced which will require disposal. The pretreatment and disposal practices required will depend on site-specific requirements.

Corrective Action Application: Case 1 - Groundwater at the MEMOREX Computer Tape Plant (Santa Clara, California) was contaminated by a leaking underground solvent storage tank (Skladany et al., 1987). Chemical analysis of the groundwater identified the presence of methyl ethyl ketone (MEK) up to 500 ppm; xylenes together with ethyl benzene up to 40 ppm; cyclohexanone up to 30 ppm; cyclohexanol up to 10 ppm; acetone up to 10 ppm; and toluene, tetrahydrofuran, 2-butanol, and methyl propyl ketone each less than 1 ppm. A biological

system consisting of two submerged fixed-film biological reactors in series was designed for treatment of the contaminated groundwater, as shown in Figure 25. By operating the reactors in series, the first unit was used to remove the bulk of the contaminants present. The second unit acted as a biological polishing unit. The design permitted one of the bioreactors to be removed or bypassed as the groundwater contaminant concentration decreased over time. Following the bioreactors, to ensure that the effluent met all applicable discharge criteria, were cartridge filters (to remove suspended solids) and two carbon units (each containing 600 pounds of carbon). The treatment system was designed to handle a continuous flow of 15 gallons per minute (gpm) and to attain effluent MEK concentrations of less than 1 ppm and other total organics concentrations of less than 100 ppb. Initial influent analysis indicated that MEK concentration to the biotreatment system was in the order of 510 ppm, at a flow rate of 8 gpm. Subsequently, additional solvent-contaminated wastes at the site also required treatment; therefore, the groundwater/solvent wastes biotreatment system was revised as shown in Figure 26. The major contaminants treated at the plant continued to be MEK and cyclohexanone.

Case 2 - The Hyde Park Landfill site, located in an industrial complex in the extreme northwest corner of Niagara, New York, was used from 1953 to 1975 as a disposal site for an estimated 80,000 tons of chemical waste, including chlorinated hydrocarbons. A compacted clay cover was installed in 1978 over the landfill and a tile leachate collection system was installed in 1979. Hazardous compounds such as ortho-, meta- and para-chlorobenzoic acid; toluene; ortho- and meta-chlorotoluene; 3,4-dichlorotoluene; and 2,6-dichlorotoluene were detected in the leachate (Irvine et al., 1984). Since 1979, the existing leachate treatment system has used activated carbon as the technology for removing organic carbon. Although

Figure 25. DETOX H-series submerged fixed-film biological reactor (Skladany et al., 1987).

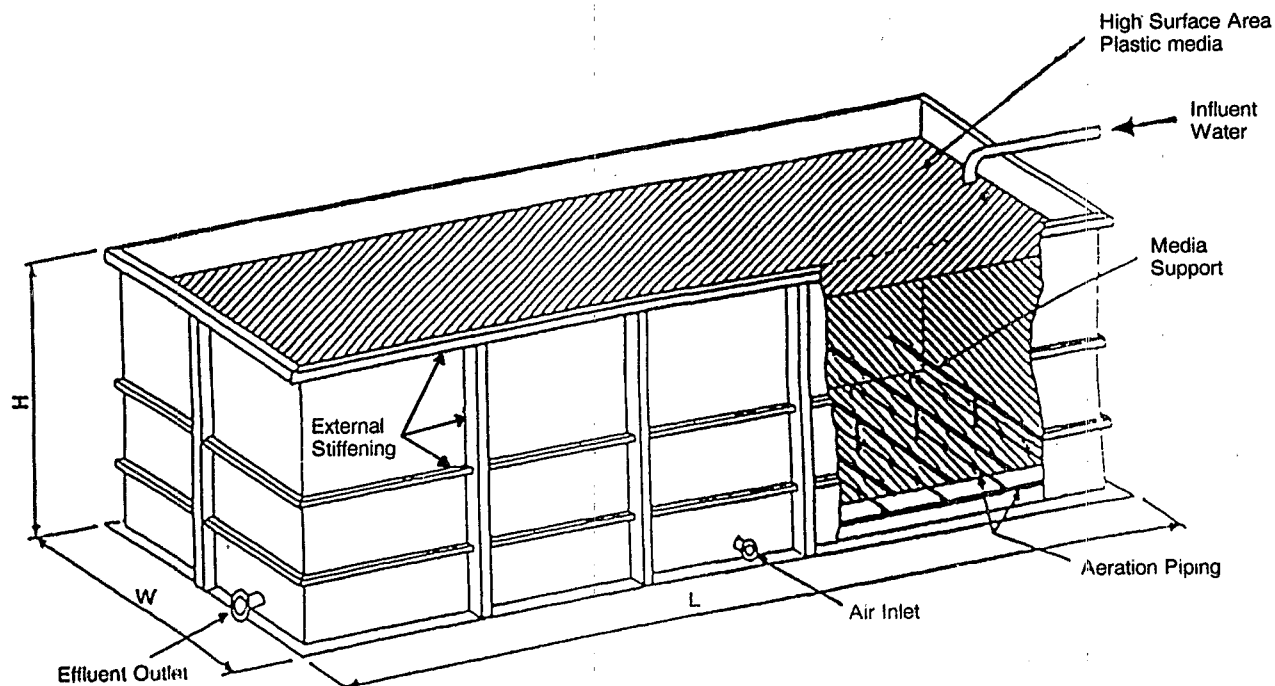
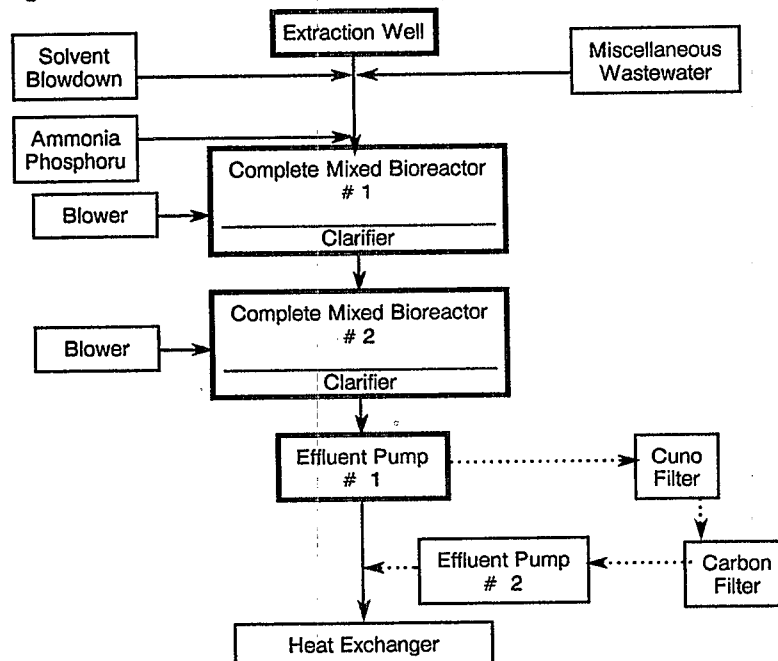


Figure 26. Process diagram for revised groundwater and solvent wastes biological treatment system.



producing a suitable quality effluent, the treatment of Hyde Park leachate by conventional carbon technology was unacceptable from an economic standpoint. For the purchase of carbon alone, the cost forecast was \$21 million over a 10-yr period (Irvine et al., 1984).

Review of several alternative technologies to reduce the load of organic carbon on the activated carbon system produced the following conclusions. The organic constituents of the leachate (which accounts for about 60 percent of the combined wastewater volume but more than 80 percent of the total organic

loading to the existing adsorption system) were found to be easily biodegraded. Biological pretreatment of the combined wastewater in SBRs was capable of reducing the carbon requirements by 90 percent (Ying et al., 1986).

Subsequently, biological/physical treatment of leachate with an activated carbon-enhanced sequencing batch bioreactor (PAC-SBR) was analyzed to determine whether the improved treatment by simultaneous adsorption and biodegradation in the SBR would produce an acceptable effluent without post-treatment in the existing granular activated carbon adsorber (Ying et al., 1986).

In-Situ Biological Treatment

Because biological activity is frequently occurring in the natural environment, the key to in-situ bioremediation involves providing those conditions which will enhance biodegradation. In-situ biological treatment requires the application of fundamental nutrients or feed augmentation to promote biological growth to a contaminated groundwater or soil.

Technology Description: In-situ biological treatment is site-specific, but in general may require the injection of nutrients, oxygen and microbial populations to degrade the organic material present. Usually, extraction wells are used to pump groundwater from beneath the site for use as a carrier for the supplemental materials which need to be applied (either to the groundwater or the soil) in order to provide the appropriate environment for biodegradation.

Applicability/Limitations: In-situ treatment is applicable to sites where the removal of the contaminated material would be difficult and in which biodegradation is currently taking place to a limited degree. This would include sites close to structures, along active railroad tracks, and where a large volume of contaminated soil or groundwater requires treatment. The limitations of in-situ bioremediation are associated with the ability to achieve adequate contact of the biomass with the waste in the underground environment and to determine the degree of degradation achieved by the treatment process.

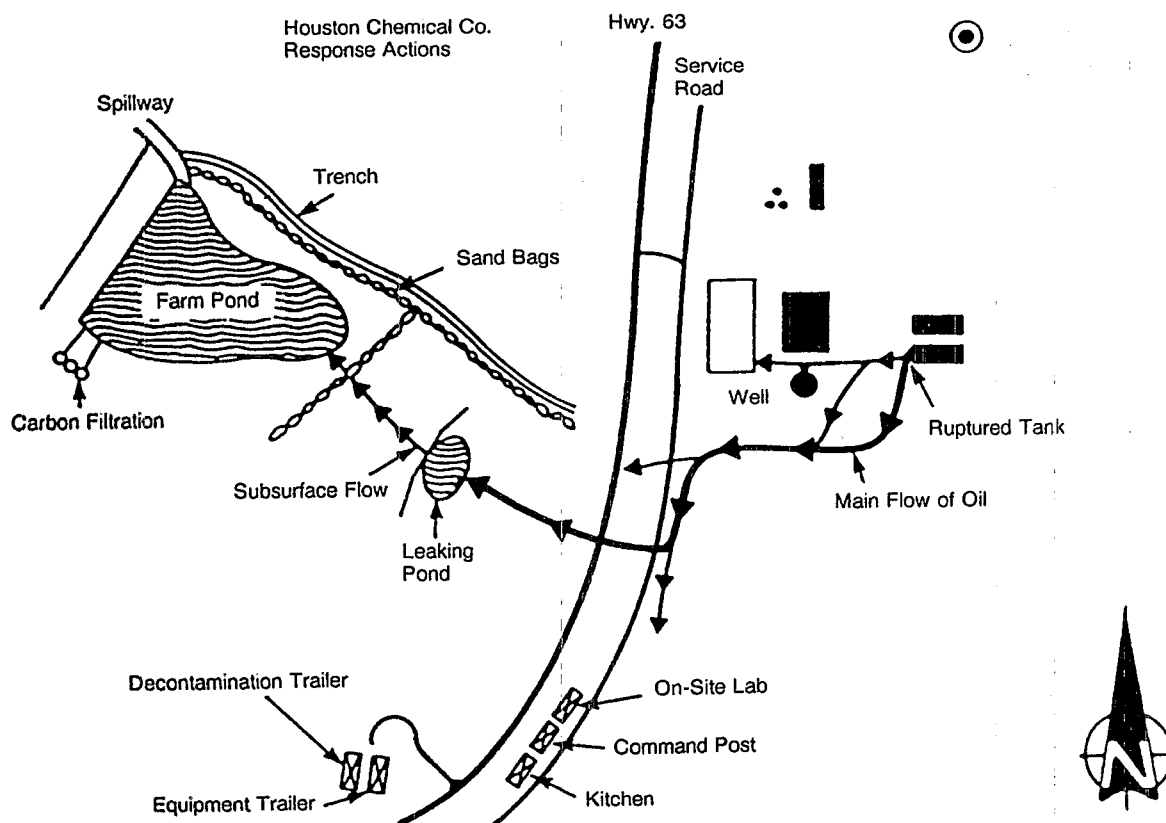
Corrective Action Application: Case 1 - A spill occurred at the Houston Chemical Company (located in Texas County, Missouri) in June 1979 (U.S. EPA, 1984). An estimated 15,000 gallons of a 5 percent solution of pentachlorophenol (PCP) in diesel oil was released as shown in Figure 27. The emergency physical cleanup operations performed at the site were:

- Skimming and vacuuming floating PCP/oil from the catch basin and pond;
- Excavating and removing contaminated soil from the PCP/oil spill path and from the farm pond bottom;
- Constructing surface water diversions around the farm pond; and
- Sealing of the well at the plant site.

The water in the farm pond was treated by carbon adsorption and returned to the pond. The biotreatment operations performed at the pond consisted of the inoculation with nonindigenous microbes for the purpose of degrading the low concentrations of PCP/oil remaining in the water and soil. Mechanical aerators were installed to provide oxygen. PCP levels were reduced using a bioremediation from a range of 250-400 µg/l to a value of 10 µg/l (the clean up objective). Subsequently, these concentrations rose to 400 µg/l, but it was anticipated that continued biodegradation at the site would occur. Since this was an emergency response action, no follow up monitoring of the site was performed.

Case 2 - At a midwestern industrial facility, two of the seven 6000-gal storage tanks were leaking fuel oil and waste solvents. The underground vault (25 ft x 70 ft x 12 ft deep) contained seven 6000-gal tanks for storing clean fuel oils and waste solvents from the laboratory facility. Groundwater contamination was confined primarily to the underground vault, but some dissolved hydrocarbons were detected in the clay stratum immediately adjacent to the tank. Soils throughout the vault were saturated with aromatic and aliphatic hydrocarbons. Total contamination was calculated to be 655 gallons of free products (solvents/fuel mixture) and 300 to 900 gallons of adsorbed hydrocarbons (Brenoel and Brown, 1985). A two phase remediation approach was chosen. In the first phase, free products were recovered. In the second phase of remediation, biostimulation was employed. The basic elements of the installed biostimulation process included a groundwater circulation system to sweep the contaminated area (i.e., a system of injection and recovery wells) and nutrient and oxygen injection capabilities. The nutrients were required for stimulation of the bacteria and controlled degradation of hydrocarbons. Two formulations were used: a blend of ammonium chloride and sodium phosphates and a formulated oxygen-enhancement solution. Because the available oxygen level was considered critical to maintaining a rapid rate of degradation, the oxygen-enhancement solution was added continuously. An activated carbon system was utilized for further reduction of residual hydrocarbons in the groundwater in the final step of remediation. The dissolved hydrocarbon levels were reduced to less than 10 ppb (Brenoel and Brown, 1985, 1984).

Figure 27. Houston Chemical Co. response actions (EPA/540/2-84/002b, 1984).



Engineered Processes to Achieve Reduction

Anaerobic treatment of hazardous wastes has not been widely used in above ground reactors or in situ. All anaerobic biological treatment processes achieve the reduction of organic matter to methane and carbon dioxide in an oxygen-free environment. This is accomplished by using cultures of bacteria which include facultative and obligate anaerobes. Anaerobic bacterial systems include hydrolytic bacteria (catabolize saccharides, proteins, lipids); hydrogen producing acetogenic bacteria (catabolize the products of hydrolytic bacteria, e.g., fatty acids and neutral end products); homolactic bacteria (catabolize multicarbon compounds to acetic acid); and methanogenic bacteria (metabolize acetic and higher fatty acids to methane and carbon dioxide). The strict anaerobes require totally oxygen-free environments and oxidation reduction potentials of less than $-0.2V$. Microorganisms in this group are commonly referred to as methanogenic consortia and are found in anaerobic sediments or sewage sludge digesters. These organisms play an important role in reductive dehalogenation reactions, nitrosamine degradation, reduction of epoxides to olefins, reduction of nitro groups, and ring fission of aromatic structures.

Technology Description: Available anaerobic treatment concepts are based on such approaches as the classic well-mixed system, the two-stage system and the fixed bed. In the well-mixed digester system, a single vessel is used to contain the wastes being treated and all bacteria must function in that common environment. Such systems typically require long retention times and the balance between acetogenic and methanogenic populations is easily upset. In the two stage approach, two vessels are used to maintain separate environments, one optimized for the acetogenic bacteria (pH 5.0), and the other optimized for the methanogenic bacteria (pH 7.0). Retention times are significantly lower and upsets are uncommon in this approach. The fixed bed approach (for single or 2-staged systems) utilizes inert solid media to which the bacteria attach themselves and low-solids wastes are pumped through columns of such bacteria-rich media. Use of such supported cultures allows reduced retention times since bacterial loss through washout is minimized. Organic degradation efficiencies can be quite high. A number of proprietary engineered processes based on these types of systems are actively being marketed, each with distinct features but all utilizing the fundamental anaerobic conversion to methane and carbon dioxide.

Applicability/Limitation: These processes are used to treat aqueous wastes with low to moderate levels of organics. Anaerobic digestion can handle certain halogenated organics better than aerobic treatment. Stable, consistent operating conditions must be maintained. Anaerobic degradation can take place in native soils but when used as a controlled treatment process, an air-tight reactor is required. Since methane and CO₂ gases are formed, it is common to vent the gases or burn them in flare systems. However, volatile hazardous materials could readily escape via such gas venting or flare systems. Thus, controlled off-gas burning is required. Alternatively, depending on the nature of the waste to be treated, the off-gas could be used as a source of energy.

To date, the logistics for achieving controlled anaerobic conditions for in-situ surface treatment have not been developed. In the subsurface environment, it has been shown that anaerobic conditions can be achieved after aerobic biodegradation has depleted the oxygen. Anaerobic conditions can be controlled in above-ground reactors. Thus aqueous waste streams can be anaerobically biodegraded whether in a reactor or in situ. Soils can also be anaerobically treated in an above ground reactor. The amount of oxygen present in subsurface soils and surface soils cannot be easily controlled, therefore anaerobic treatment is not generally appropriate.

Residuals Produced: Some biomass is produced which will require disposal. The disposal practices required will depend on site-specific requirements.

Corrective Action Application: At the Turi Landfill in Orange County, New York, bench-scale studies at room temperature were conducted for the anaerobic treatment of sanitary landfill leachate. Leachate collected directly from the Turi landfill site was used in test runs conducted in continuous operation for more than 6 months. Highly variable characteristics of the leachate used in the study was exemplified by CODs ranging from 2,000 to 35,000 mg/l, BOD₅s from 1,800 to 24,000 mg/l, and ammonia nitrogen from 50 to 500 mg/l. Concentrations of detectable priority pollutants were also found in the leachate. An anaerobic fixed-film reactor (with a volume of 5.78 gal and with a controlled rate of sludge recycling) was operated with upflow feeding at organic loadings between 0.51 and 5.46 lb COD/ft³-day and hydraulic detention times of 6.9 to 10.3 days (Mureebe et al., 1986). The test runs resulted in filtered COD removals from 92 to 94 percent, unfiltered BOD₅ removals of 90 to 94 percent, and ammonia removal from 40 to 50 percent.

Thermal Processes for Corrective Action

What is Incineration?

Corrective Action utilizing incineration can be applied to most organic-bearing wastes under various conditions. Wastes may be burned which contain relatively high water content, are largely inorganic in nature (i.e., they possess high ash content), or are in the solid or semi-solid state. The primary question is: When should incineration be chosen for application as opposed to other technologies? To decide whether incineration is the best technology for a specific waste, consideration must be given to the following issues:

1. Limitations which arise from the quantity or nature of the waste;
2. The environmental impact of incineration, including stack and fugitive emissions;
3. The requirements for disposal of residues, i.e., ash and air pollution control (APC) residues;
4. Permitting issues.

Incineration is an oxidative process which is used for:

- detoxification and sterilization
- volume reduction
- energy recovery
- by-product chemical recovery

The incineration process may be viewed as consisting of four parts: (1) preparation of the feed materials for placement in the incinerator (pretreatment), (2) incineration or combustion of the material in a combustion chamber, (3) cleaning of the resultant air stream by air pollution control devices (APCDs) which are suitable for the application at hand, and (4) disposal of the residues from the application of the process (including ash, and air pollution control system residues).

Applicability Based on Waste Type

Thermal processes are typically used for highly toxic waste or highly concentrated organic wastes. If the waste contains PCB, dioxins, or other toxic substances, incineration should be chosen in order to assure destruction. If the wastes contain greater than 1000 parts per million of halogens (chlorinated materials), it would probably be desirable to select incineration of these wastes, after consideration of other options. In any case, a material may be incinerated or used as a fuel if the heat content is greater than 8500 BTUs per pound or, if between 2500 and 8500, it may be incinerated with auxiliary fuel. The waste components of concern are halogens, alkali metals and heavy metals.

Applicability Based On Waste Form

Incineration processes are available to destroy organics in liquids, solids/sludges, soils and gases.

Selection Strategy

Simple strategies (as shown in Figures 28 and 29) exist for evaluating incineration as an option, given the waste's characteristics. This decision logic will assist in planning for possible use of incineration for hazardous waste applications. If the wastes contain highly toxic substances (e.g., dioxins), or compounds of special interest such as PCBs, the incineration or destruction option is an attractive one (the first two decision diamonds on Figure 28). If wastes contain high concentrations of halogens or recoverable heat value (the next two decision diamonds), the possibility for recovery and/or alternate pretreatment should be examined. For this option, the series of boxes to the right of the diagram should be used. Finally, waste with low-heat value could be burned with supplemental fuel. Thus, the process shown on Figure 29 may be used to evaluate incineration among the treatment technologies available. If incineration is selected, the next step is the selection of the type of combustion device. The physical form, metal content, and water content are the major considerations for the selection. Pretreatment methods exist for wastes prior to incineration.

Thermal Processes and Their Application

Once the decision is made to incinerate the material, the type of incinerator which is selected is largely dependent on the matrix in which the waste is located. Table 10 indicates the application of various thermal processes for liquids, solids/sludges, soil and gases.

Incineration of Liquids

The types of incinerators which can be employed for incineration of liquid wastes include:

- Liquid injection furnaces
- Plasma arc incinerators
- Rotary kilns (discussed under the incineration of solids)

Liquid Injection

Technology Description: Liquid waste material is introduced to the combustion chamber by means of specially designed nozzles. Different nozzle designs result in various droplet sizes which mix with air and fuel as needed. Following combustion, the resulting gases are cooled and treated to remove particulates and to neutralize acid gases. Pretreatment (such as blending) may be required for feeding some wastes to specific nozzles in order to provide efficient mixing

with the oxygen source and to maintain a continuous homogeneous waste flow. In general, the more finely atomized liquids will combust more rapidly and more completely. Operating temperatures range from 1200 to 1300°F and the gas residence time ranges from 0.1 to 2 seconds. Typical heat output ranges from 1 to 100 MMBtu/hr. A typical configuration for a liquid injection incinerator is presented in Figure 30.

Applicability/Limitations: Liquid injection incineration can be applied to all pumpable organic wastes including wastes with high moisture content. Care must be taken in matching waste (especially viscosity and solids content) to specific nozzle design. Particle size is a relevant consideration so that the wastes do not clog the nozzle. Emission control systems will probably be required for wastes with ash content above 0.5 percent (particulate control) or for halogenated wastes (acid gas scrubbers).

Residuals Produced: Liquid injection incinerators produce ash which may require application of a post treatment technology prior to disposal. The by-products from the emission control devices may also require further treatment prior to disposal.

Plasma Arc

Technology Description: The developmental plasma arc process functions by contacting the waste feed with a gas which has been energized into its plasma state by an electrical discharge. The plasma torch acts as one electrode and the hearth at the bottom of the reactor acts as the second electrode. The discharge of electricity between the two electrodes causes the centerline temperatures in the plasma to reach 9000°F. A small amount of gas is introduced into the centerline region and is ionized. The ionized gas molecules transfer energy to the waste to cause pyrolysis of the waste. Since the process is pyrolytic, the scale of the equipment is small, especially considering the high throughput rates. This characteristic makes it potentially attractive for use as a mobile unit. Gaseous emissions (mostly H₂, CO), acid gases in the scrubber and ash components in scrubber water are the residuals. The system's advantages are that it can destroy refractory compounds and typically the process has a very short on/off cycle. The system components for the plasma arc process is presented in Figure 31.

Applicability: This process is applicable to liquid (pumpable) organic wastes and finely divided, fluidizable sludges. It may be particularly applicable to the processing of liquid wastes with a high chlorine, pesticide, PCB or dioxin content. Sludges must be capable of being fluidized by the addition of a liquid. Waste streams must be free of (or preprocessed to remove) solids, which prevent satisfactory atomization.

Figure 28. Conceptual strategy for determining burnability.

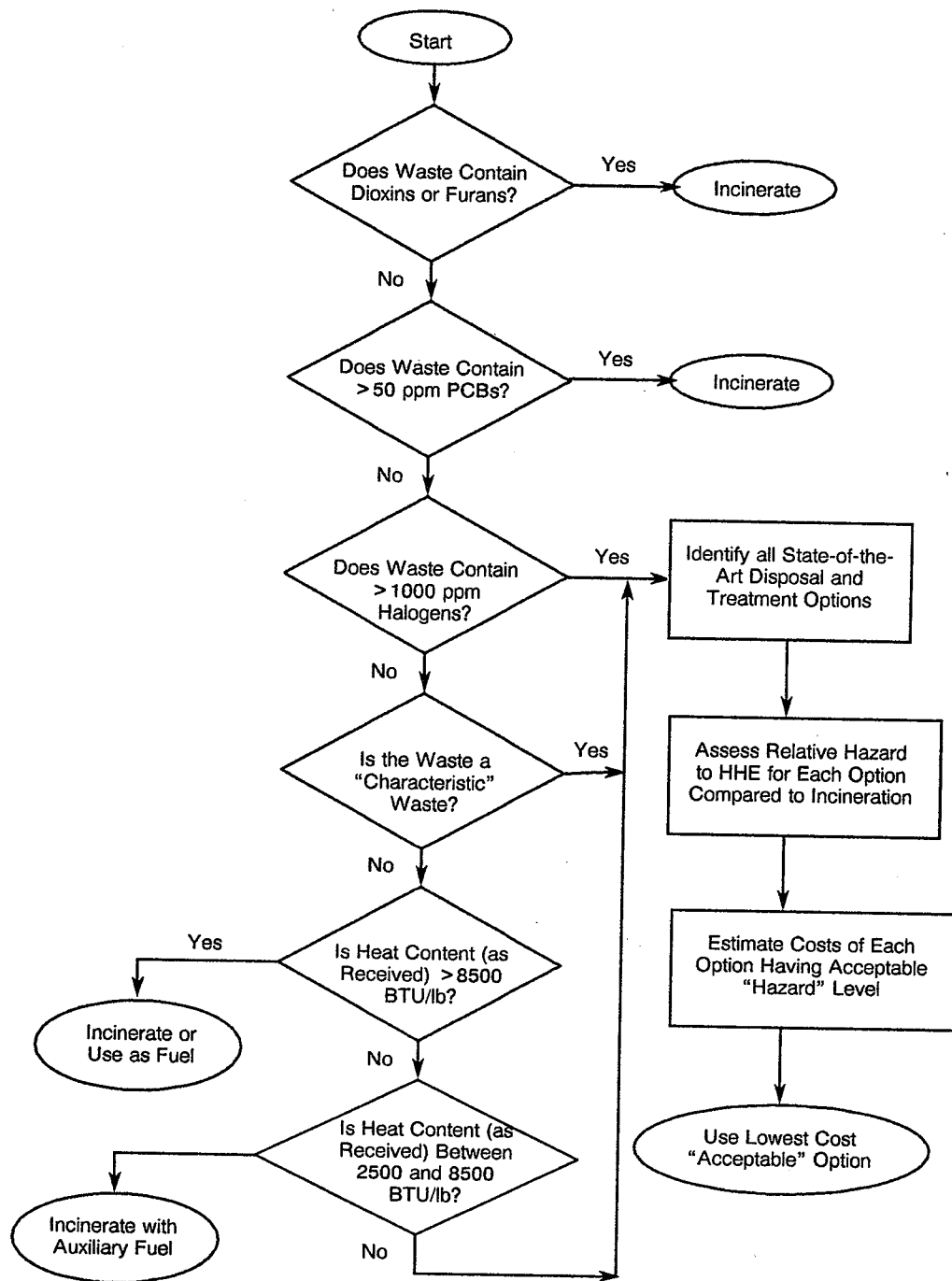


Figure 29. Pretreatment option logical decision flow chart.

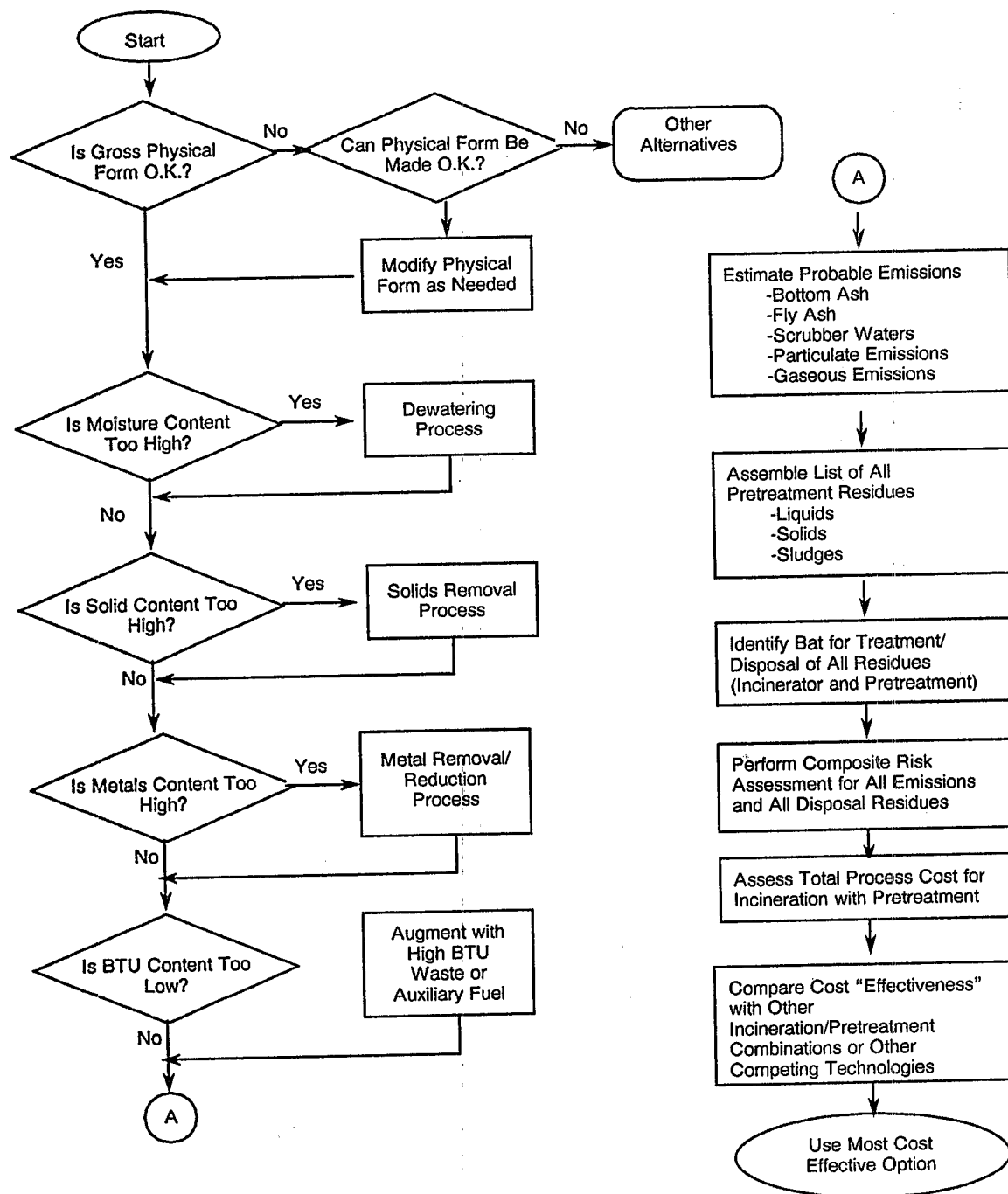


Table 10. Incineration Type for Various Waste Matrices

	Liquids	Solid/Sludges	Soil	Gases
Liquid injection incinerator	x			
Plasma Arc	x			
Rotary Kiln		x	x	
Fluidized Bed	x	x		
Circulating Bed		x		
Infrared		x	x	
In-situ Vitrification			x	
Afterburners				x

Residuals Produced: The plasma arc process produces ash which may require post treatment to make it suitable for disposal. The wet scrubber blowdown may require treatment prior to disposal.

Solids/Sludges

The thermal processes applicable to detoxify organics in a solid/sludge matrix include the following incinerators:

- Rotary kiln
- Fluidized bed
- Circulating bed
- Infrared

Rotary Kiln

Technology Description: A rotary kiln incinerator is essentially a long, inclined tube that is rotated slowly. Wastes and auxiliary fuels are introduced to the high end of the kiln and the rotation constantly agitates (tumbles) the solid materials being burned. This tumbling causes a great amount of solids mixing and allows for improved combustion. Rotary kilns are intended primarily for solids combustion, but liquids and gases may be co-incinerated with solids. Exhaust gases from the kiln pass to a secondary chamber or afterburner for further oxidation. Ash residue is discharged and collected at the low end of the kiln. Figure 32 illustrates a rotary kiln system.

Applicability/Limitations: Most types of solid, liquid, and gaseous organic waste or a mixture of these wastes can be treated with this technology. Explosive wastes and wastes with high inorganic salt content and/or heavy metals require special evaluation. This operation can create high particulate emissions which require post-combustion control.

Residuals Produced: Exhaust gases require acid gas and particulate removal through the use of a gas scrubber and the ashes may require solidification before landfilling.

Corrective Action Applications: Case 1 – The U.S. Army Toxic and Hazardous Materials Agency

(USATHAMA) completed a trial burn of explosive, contaminated soil in a rotary kiln (Noland, 1984). Soil contaminated from red and pink water lagoons was successfully burned. A transportable rotary kiln system was set up. The technology by Therm-All, Inc., had been used in industry for destruction of solid wastes. The normal screw feed system was not used, due to fear of a soil explosion during the extruded plug feed process. Therefore, the soil was placed in combustible buckets and individually fed by a ram into the incinerator. The feed rate was 300 to 400 lb/hr and the operational temperature was 1200° to 1600°F in the kiln and 1600° to 2000°F in the secondary chamber.

A DRE of 94.99 percent was reported. The flue gases were cooled in a heat exchanger prior to entering a baghouse for particulate emissions control.

Case 2 – A mobile rotary kiln incinerator was used at the Sidney Mines site, Hillsborough County, Florida, to burn nonhazardous oil-contaminated sand and sludge (Hatch, 1985). The site did not require a RCRA permit since the waste matrix passed the EP toxicity test and was not hazardous. The dry processed soil was captured in a bin and tested by the EP toxicity method for leachable heavy metals prior to disposal at the nearby county landfill. The flue gases were cooled by a boiler prior to entering a water quench and steam ejector particulate system. The boiler generates steam to operate the particulate emissions control ejector. The steam ejector also serves as the source and regulator for the negative draft through the combustor, and thus the system does not have an induced-draft fan.

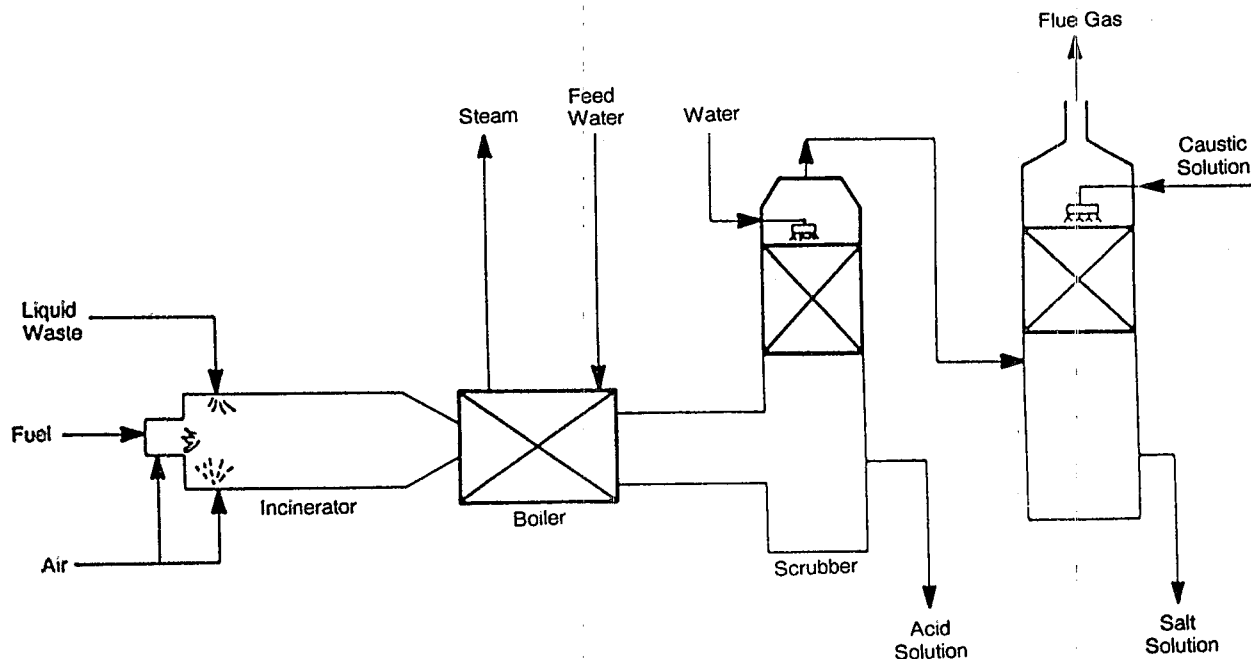
The incinerator processed about 2.25 tph due to the high thermal value of the oil. The system could handle 4 to 6 tph of low-energy soils. The system experienced the following problems:

- clogging of front-end waste feed equipment,
- loss of refractory bricks sooner than expected, and
- carry-over of fine solids into the horizontal secondary chamber and restriction of the flue gas flow.

Fluidized Bed

Technology Description: Fluidized bed incinerators utilize a very turbulent bed of inert granular material (usually sand) to improve the transfer of heat to the waste streams to be incinerated. Air is blown through the granular bed materials until they are "suspended" and able to move and mix in a manner similar to a fluid, i.e., they are "fluidized". In this manner, the heated bed particles come in intimate contact with the wastes being burned. The process requires that the waste be fed into multiple injection ports for successful treatment. Advantages

Figure 30. Liquid injection incineration system



of this technology include excellent heat transfer to the material being incinerated and a long solids-retention time. An off-shoot of this technology is a circulating bed combustor. The configuration of a fluidized bed reactor is presented in Figure 33.

Applicability/Limitations: Fluidized beds require frequent attention for maintenance and cleaning purposes. This treatment is ideal for slurries and sludges but not for bulky or viscous wastes. The waste particles should be of a certain size and be homogeneous. Wastes must have a low sodium content and a low heavy metal content. Some refractory wastes may not be fully destroyed since these units operate at low combustion temperatures (750° to 1000°C).

Residuals Produced: Fluidized bed incineration produces no separate ash as such, but solids are carried over in the gas stream and will require removal. Residuals from the air pollution control devices may require additional treatment prior to disposal.

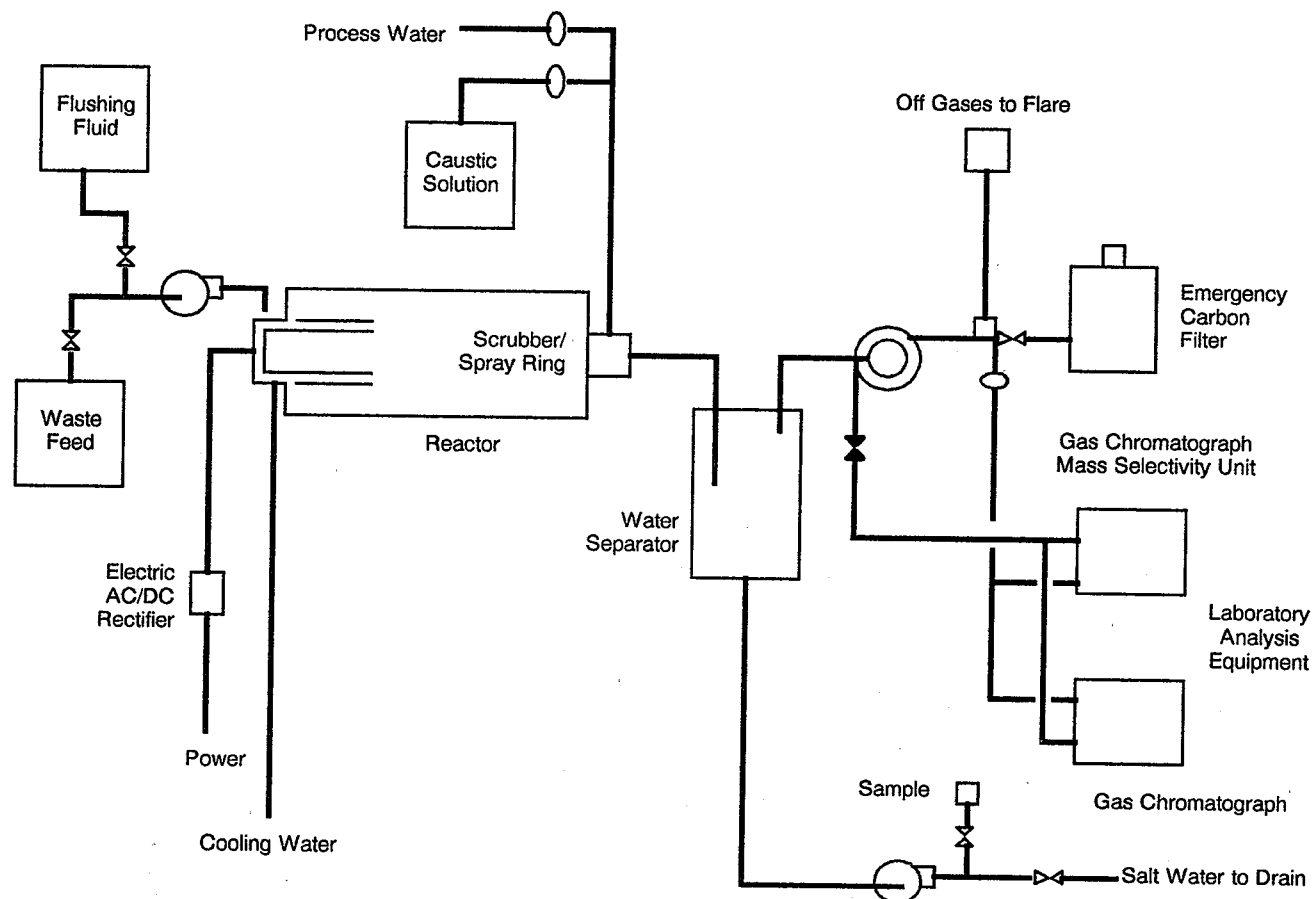
Corrective Action Application: Fluidized bed incineration has been used to incinerate municipal wastewater treatment plant sludge, oil refinery waste, some pharmaceutical wastes, and some chemical wastes including phenolic waste, and methyl methacrylate. Heat recovery is possible.

Circulating Bed

Technology Description: The circulating bed combustor (Figure 34) is designed to be an improvement over conventional fluidized beds. The system operates at higher velocities and finer sorbents than fluidized bed systems. This permits a unit that is more compact and easier to feed. The unit also produces lower emissions and uses less sorbent materials than the fluidized bed systems. No off-gas scrubber is necessary in the circulating bed combustor and heat can be recovered as an added benefit. The key to the high efficiency of the circulating bed combustor is the high turbulence that is achieved within the combustor. This feature allows efficient destruction of all types of halogenated hydrocarbons including PCBs and other aromatics at temperatures less than 850°C. Acid gases are captured within the combustion chamber by limestone in the bed. A baghouse is needed for particulate control. Compounds containing high levels of phosphorus, sulfur, cyanide, etc. can be processed with low emissions of NO_x, CO and acid gases. In addition to the turbulence, a large combustion zone with uniform and lower temperature throughout also contributes to high efficiency. The circulating bed combustor also features longer residence time of the combustibles and sorbents in the combustion zone.

Applicability/Limitations: The system is capable of treating solids, sludges, slurries and liquids. The high degree of turbulence and mixing ensures treatment of a wide variety of wastes. The waste

Figure 31. Schematic of plasma arc system.



Source: Westinghouse Plasma Systems

however, must be fairly homogeneous in composition when fed to the combustor, since it is usually introduced at only one location. An additional benefit of the circulating bed combustor is the possibility of heat recovery. The combustion chamber can be of "waterwall" construction.

Residuals Produced: Circulating bed incinerators produce no ash. Solids are carried over in the gas stream and require removal. Residuals from the air pollution control device may require further treatment prior to disposal.

Corrective Action Application: Circulating fluidized bed incinerators are ready for full-scale testing under the EPA SITE Program. A unit is now in the RCRA permitting process.

Infrared

Technology Description: Infrared radiators can be used as the heat source in the destruction of hazardous waste. This system (Figure 35) is made up of a primary chamber consisting of a rectangular carbon steel box lined with layers of a light weight,

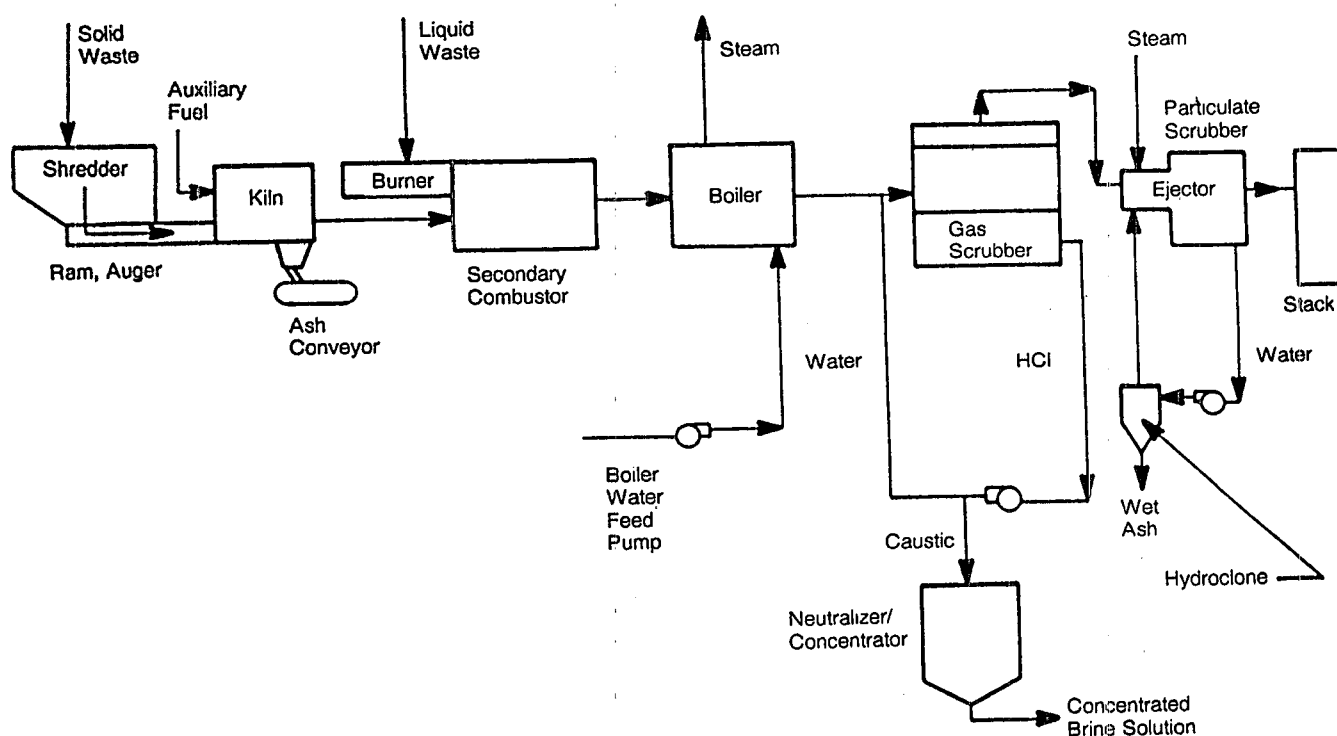
ceramic fiber blanket. Infrared energy is provided by silicon carbide resistance heating elements. The material to be processed is conveyed through the furnace on a woven wire belt. Solids are pyrolyzed on the hearth. Sufficient air (or oxygen) is introduced to fully combust the off-gases. When the waste reaches the discharge end of the furnace it drops off the belt into a hopper. Advantages include a quiescent combustion zone, which results in low particulate emissions; reduced gaseous pollutant emissions; low fossil fuel usage; and up to 50 percent operational turndown capacity. This system allows a high degree of control, and long-residence times for solids are achievable.

Applicability Limitation: This technology is used primarily to treat solids, sludges and contaminated soils, but liquid or gaseous injection systems are available.

Soils

Applications of thermal processes to contaminated soils are somewhat limited. Two processes, rotary

Figure 32. Rotary kiln incineration system.



kilns and in-situ vitrification, offer a mechanism to detoxify organic contaminated soils.

Rotary kilns, as described previously, can be used to incinerate materials which can be excavated and fed into the kiln. Vitrification is a process which can be used without removing the soil and is described below.

Vitrification

Technology Description: Vitrification is a process whereby hazardous wastes are converted into a glassy substance by means of very high temperatures. The process is carried out by inserting large electrodes into contaminated soils, which must contain significant levels of silicates. Graphite on the surface connects the electrodes to the soil. High current of electricity passes through the electrodes and soil. The resultant heat in the soil causes a melt that gradually works downward through the soil.

Some organic contaminants are volatilized and escape from the soil surface and must be collected by a vacuum system. Inorganics and some organics are trapped in the melt, which, as it cools, becomes a form of obsidian or very strong glass. When the melt is cooled, it forms a stable noncrystalline solid.

Applicability/Limitation: Vitrification was originally tested as a means of solidification/immobilization of low level radioactive materials. It may also be useful for forming barrier walls. This latter use needs testing and evaluation to determine how uniform the wall would be and to evaluate the stability of the material over a period of time.

Residuals Produced: Off-gases from the melting require treatment for volatile organics.

Corrective Action Application: This technology is currently being evaluated under the Superfund Innovative Technology Evaluation (SITE) Program.

Figure 33. Fluidized bed reactor.

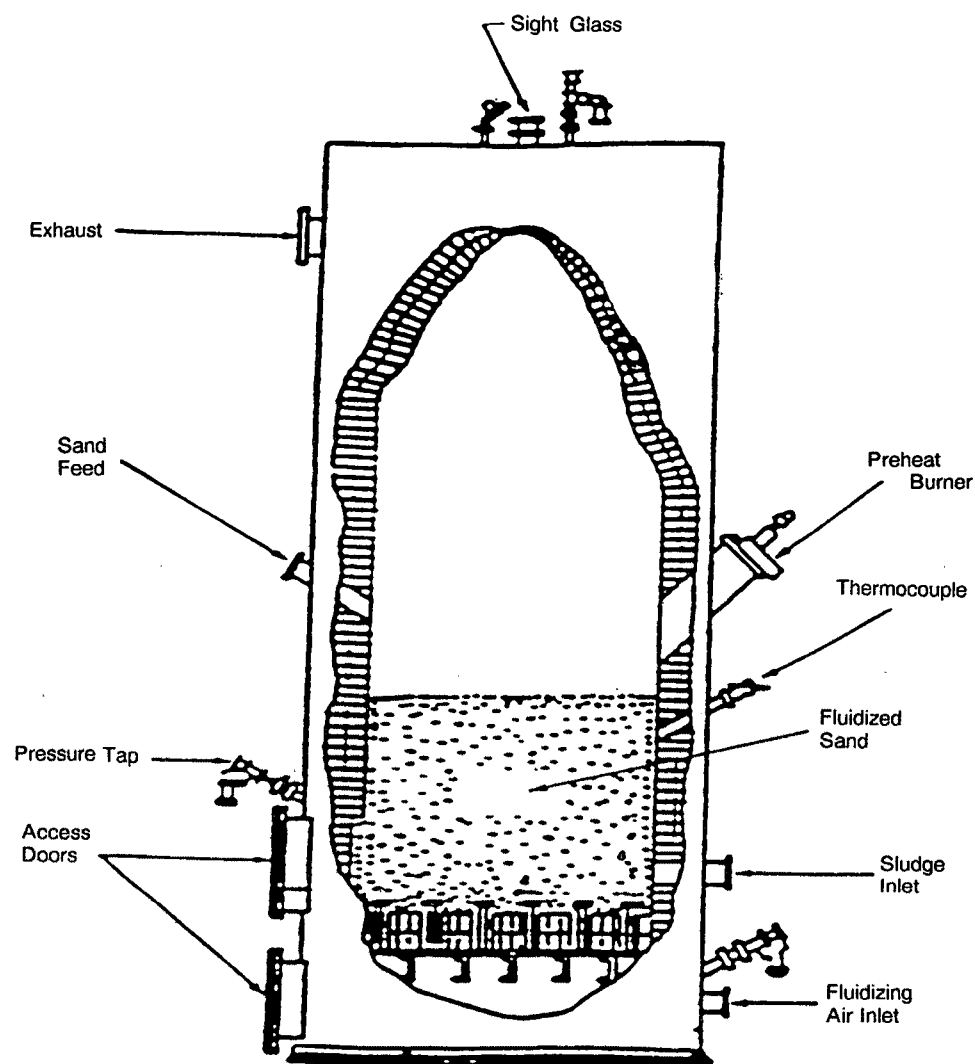


Figure 34. Circulating fluidized bed boiler.

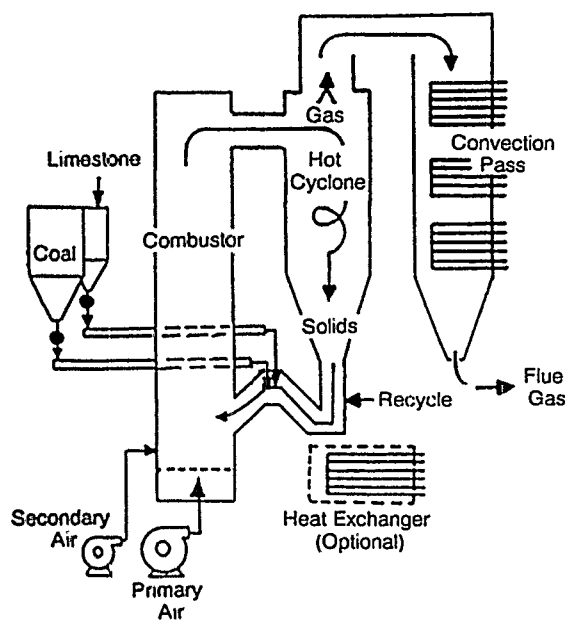
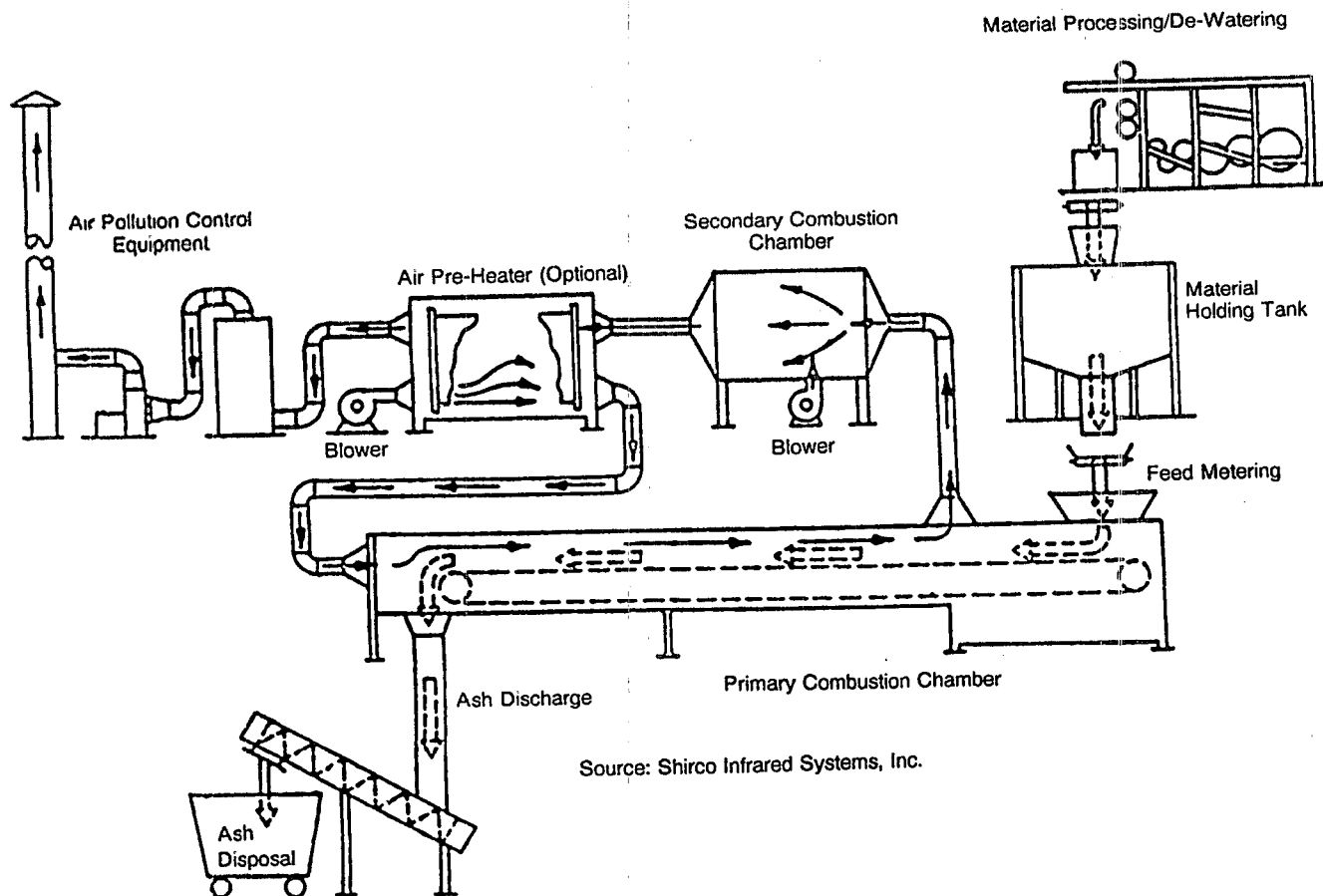
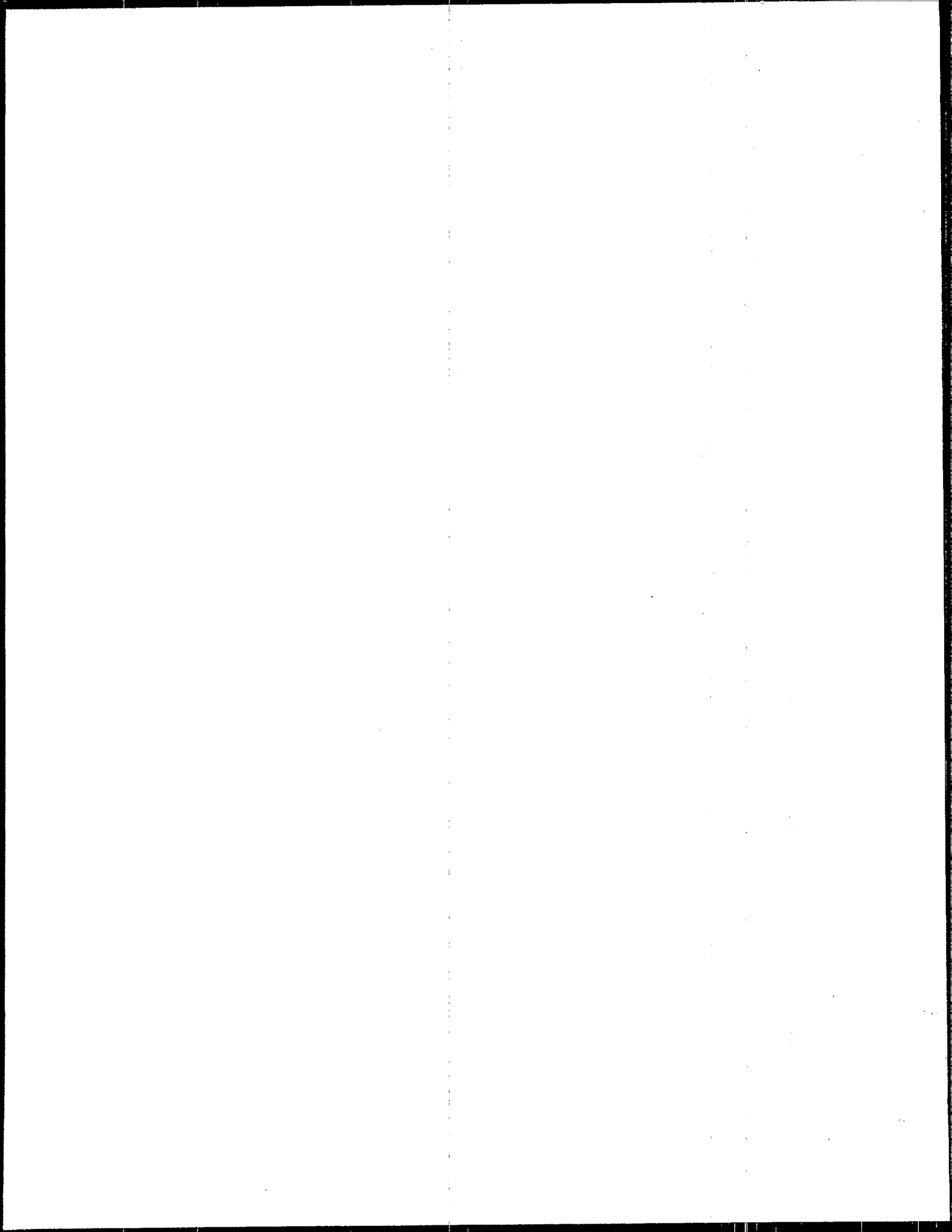


Figure 35. Process flow diagram of infrared incineration system.



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Chapter 6

Pretreatment and Post Treatment Options

Once the primary treatment alternatives have been identified for the detoxification of the waste or waste stream, other treatment technologies may be required to prepare the waste for treatment. Similarly, additional treatment technologies may be required to prepare residues from the treatment process for ultimate disposal. As shown in the review of biological processes, some technologies (e.g., pH adjustment) were needed to permit other technologies to proceed. Physical separation techniques are frequently required to prepare a waste for treatment. These pretreatment technologies are directed toward concentrating or sizing the waste to facilitate treatment. Furthermore, most treatment processes produce residues which may require additional treatment before land disposal. Solidification/stabilization processes are frequently used as post-treatment technologies to immobilize hazardous constituents in chemical sludges and incinerator ash. These solidification/stabilization technologies can also be applied to high volume, low toxicity wastes without treatment by other technologies.

Separation Techniques (Pretreatment Options)

Most treatment options for detoxifying the hazardous constituents from RCRA facilities must have a uniform feed to the process. However, the media in which hazardous constituents are located are not generally homogeneous. Thus, some form of pretreatment of the waste or waste medium will probably be required to prepare the waste for further treatment by chemical, biological or thermal means.

A Separation Strategy

With few exceptions, treatment technologies are limited to some extent by the size of the material that they are able to process. These limitations can apply to the throat of the feed devices, the inner workings of the equipment, the treatment mechanisms, or the process elements. To make these remedial technologies efficient and cost effective, separation techniques are used to make the feed stream uniform

or to isolate specific contaminants from the waste stream.

In developing a separation strategy, the size distribution of the components found in the contaminated medium can be used as a starting point. As an initial step, debris (such as rocks, etc.) can be separated from the remainder of the waste. After the debris is removed, other separation techniques can be employed to concentrate the waste further or physically manipulate the waste into a form suitable for treatment.

Debris Separation

In order to develop measures for removal of debris from the waste matrix, the general types of debris anticipated need to be identified. A composite list, based on debris found at 29 Superfund sites, was developed. The list includes cloth, glass, ferrous materials, nonferrous materials, metal objects, construction debris, electrical devices, wood existing in a number of different forms, rubber, plastic, paper, etc., as presented in Table 11. Similar types of debris would be expected at RCRA sites.

Debris with particularly good absorbent qualities such as wood, some paper products, paper, cloth materials, etc., are good candidates for shredding so that they can be included in the remediation process. Materials that are not porous and are not adsorbent are glass, plastic, metal objects, some types of construction debris, tanks, etc., are good candidates for manual or magnetic separation.

After the debris has been separated or removed, there are basically four options available for dealing with the debris:

- Do nothing.
- Pile it off to the side to be treated later.
- Shred the material so that it does not interfere with the process.
- Separate it and not include it in the process.

Table 11. Debris Identification

Cloth	Paper
- Rags	- Books
- Tarps	- Magazines
- Mattresses	- Newspaper
Glass	- Cardboard
- Bottles	- Packing
- (white, brown, green, clear, blue) Windows	Plastic
Ferrous Metals	- Buckets
- Cast iron	- Pesticide containers
- Tin cans	- Six-pack retainer rings
- Slag	- Thin plastic sheets
Nonferrous Metals	- Plastic bags
- Stainless steel	- Battery cases
- Aluminum	Rubber
- Brass	- Tires
- Copper	- Hoses
- Slag	- Insulation
Metal Objects	- Battery cases
- Autos/vehicles	Wood
- 55-gallon drums/containers	- Stumps and leaves
- Refrigerators	- Furniture
- Tanks/gas cylinders	- Pallets
- Pipes	- Plywood
- Nails	- Railroad ties
- Nuts and bolts	Electronic/Electrical
- Wire and cable	- Televisions
- Railroad rails	- Transformers
- Structural steel	- Capacitors
Construction Debris	- Radios
- Bricks	
- Concrete blocks	
- Asphalt	
- Stones and rocks	
- Reinforced concrete pipe	
- Wood	
- Steel beams	
- Asbestos insulation and roofing/siding shingles	
- Fiberglass insulation	
- Fiberglass tanks	

Separation Analysis

In selecting or investigating alternative separation and treatment technologies, there are some rules of thumb which can be useful. For example, contamination occurs on the surface of soil particles. The smaller the size of the particle, the greater is its proportionate surface area; consequently, the smaller particles have a greater relative capacity for contamination. In general, in a soil matrix that consists of large particles and small particles, a high

level of contamination would be expected in the finer fraction. Experience in site remediation has indeed shown that to be the case. Making use of this feature can reduce volumes of waste to be treated and thereby minimize treatment costs.

It should be remembered that while it is generally true that the heavier contamination is found in the finer fractions, it is not totally true. Coarser fractions can have cracks where there is room for large quantities of contamination.

In lagoons where there is liquid on the surface and a highly viscous fluid below the liquid surface, separating the water from the waste and sludge may be appropriate. The expenses for incineration of the removed sludge could be greatly reduced by removal of the water.

The chemical properties of the contaminants have to be considered when selecting separation techniques. Some of the liquids are absolutely immiscible in water, and if the process stream involves water and the contamination is liquid/liquid, then the separation technique can greatly reduce the volume of contaminated water. For example, if acetone is the contaminant of concern, a simple vapor stripping technique can be effective in making a separation. In the case of refined oil, which has a solubility limit of approximately 50 ppm, one of the oil/water separation techniques could be effective. Some general guidelines to consider are:

- If the waste stream has a high content of fine particulate matter then, by isolating particulate matter, most of the contamination would be isolated.
- If the chemicals of concern contain more than eight carbon atoms, then they tend to have a high soil adsorption.

In general, when separating two liquids, they must be immiscible and have different specific gravities before a separation technique—such as oil/water separation—would be effective. In the case of finely dispersed liquids or finely dispersed solids, if the dispersed material is below one micron in particle size, centrifuging should be considered. The use of centrifugal force on the differing densities of the material can facilitate the separation technique.

Sizing Methodology for Solids

Once the debris has been removed from the waste material, the preparation of the waste for treatment can begin. Over the years, the construction, mining, and manufacturing industries have developed various pieces of equipment that are geared for the specific purpose of separating materials and making process streams uniform. The raw materials

themselves can range in size from 1 meter down to 1 angstrom (10^{-10} meters). There are a number of devices that can be used to separate materials depending upon the form of the waste and the particle size (Figure 36). These devices utilize a difference in size, density, or their electrical or magnetic properties to make the separation. The use of any of these technologies or a combination of these technologies may be required to prepare the waste for further treatment.

Separation Technologies

The size of the particles, the medium, and the contaminant are all important factors in the selection of a separation technique. Another important consideration in selecting a separation technique is whether the process is intended to make the waste stream uniform or to isolate a portion of the waste stream for treatment.

Screens

The screen is a simple device used for the grading or separating of particles by size. Vibrating and oscillating screens are used for the same purpose, but the passing of the material is enhanced by a vibrator or oscillator, respectively. The centrifugal screen enhances the passing of the material by making use of centrifugal force and the density of the material.

Tabling

Another type of separation that utilizes the difference in densities of material is called tabling. The process can be performed either wet or dry, with dry tabling having the broader particle size range where it can be used. The device uses slotted incline planes, and the surface oscillates to move the solids. In the case of wet tabling, washing fluid removes the less dense solid fractions, and the heavier solids are collected in the grooves and moved to the collection point by the table oscillation. For example, dry tabling is used extensively in the coal industry. The undesired mineral content of mined coal is much more dense than the actual bituminous, anthracite, or lignite fractions of the coal. The ash content of the mineral-containing fraction is much higher than that of the coal fraction making separation desirable.

Another type of the tabling process is called agglomerate tabling. Here, pretreatment is involved to precipitate a particular constituent of the material so that it can be separated by the tabling process. This type of tabling is particularly useful for sludges that require pretreatment.

Cyclones

Cyclones, hydrocyclones and centrifuges utilize centrifugal force to separate material of differing

densities. The principle in the operation of these devices is that the heavier materials are thrown to the outside, and the lighter materials remain near the inside where they can be drawn off (Figure 37).

Jigging

Jigging is a separation process in which material of similar size but different densities can be separated by immersing them in a fluid that is less dense than either material. Pulsating the material up and down in the fluid is done in such a manner that different buoyancy factors are imparted to particles of differing densities (Figure 38). The lighter materials separate to the top; the heavier materials settle to the bottom. This process can also be used to separate material of the same density but different particle size. The jigging process is used extensively in the mining industry, particularly coal mining and uranium mining.

Magnetic Separator

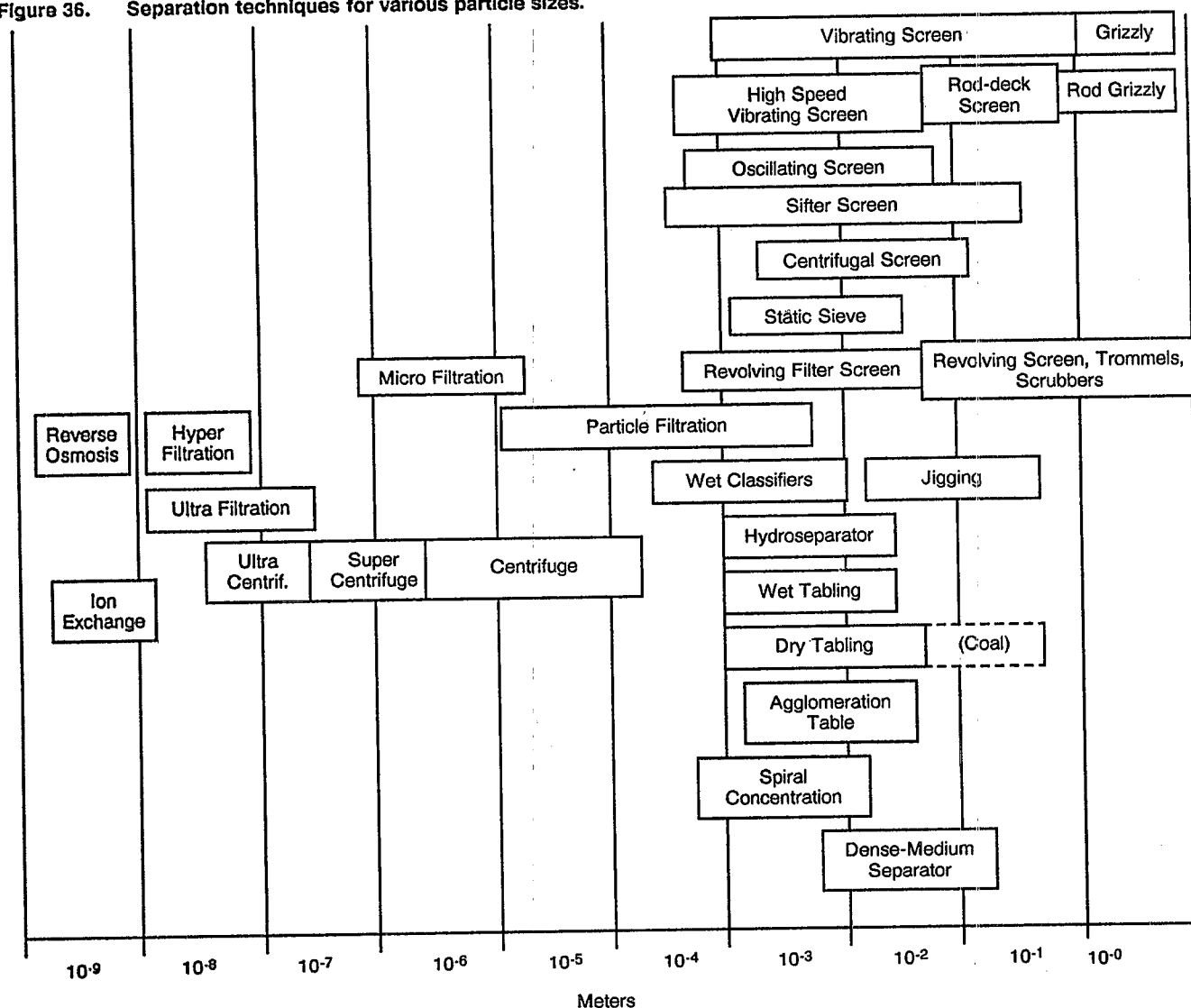
The magnetic separator is typified by a rotating drum surrounded by four stationary magnets. The material coming in from the top is composed of magnetic and non-magnetic material. As the material falls past the drum, the magnetic field will hold the magnetic material in place until it can drop down into a separate chute for magnetic materials. The non-magnetic materials, of course, will drop off prior to that point and down another chute (Figure 39).

Oil/Water Separators

Oil/water separators are another class of devices that utilize density to achieve separation. Oil/water separators have wide application at petroleum refineries, shipboard bilge water processing, and metal processing where oil and water emulsions are used as lubricants. Most oil/water separators depend upon gates or weirs and baffles to effect the oil and water separation without disturbing the operation of the rest of the device (Figure 40). This device can also include a scraper for solids removal. The effluent is discharged into the sewer or a holding basin.

Another kind of oil/water separator is a coalescing system which involves packs of parallel, inclined plates. The oil-laden fluid passes down from top to bottom across the parallel plates. As the water passes through the plates, oil tends to coalesce on the plates. The water is not passed through the plates fast enough to capture the droplets of coalescing oil. Due to the buoyant effect in the water, the coalesced oil will go back up the plates. The oil globules escape and create an oil layer at the top of the device where it can be skimmed off with a physical skimming device. The coalescing oil/water separators utilize a sediment trap so that solids do not get into the parallel plates. The treated water, after going through the plates,

Figure 36. Separation techniques for various particle sizes.



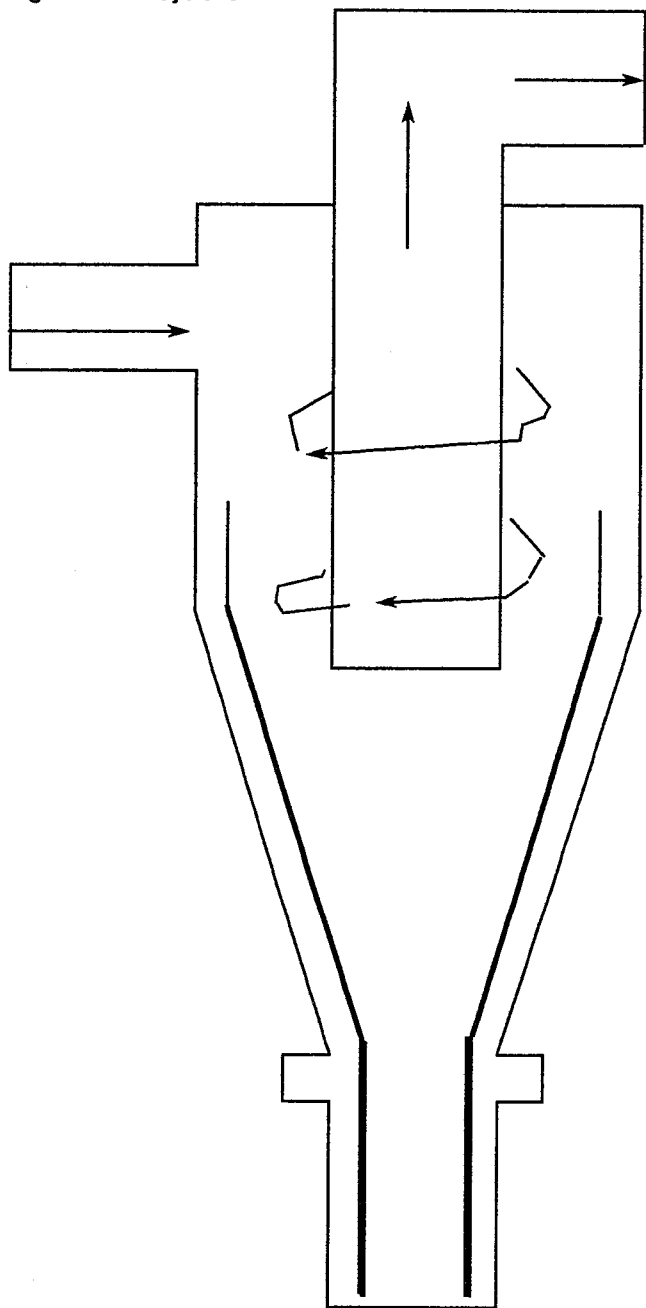
goes into an outlet chamber where residual oil will tend to float. The chamber outlet is below the outer surface so there is less likelihood of taking the residual oil product to the outlet valve (Figure 41). The parallel plate process is not the only type of coalescent equipment that is used. There are a number of different types of coalescent elements.

Soils Washing System

A soils washing system is a system designed to separate soil into component parts and, in the process, do some scrubbing and washing of contaminants (Figure 42). The one shown is a mobile system developed by the EPA. The waste feed is placed in the top hopper. Inside the first chamber is a screen section. This is a rotating screen or trommel. It has a wedge wire screen, and is designed so that if particles do get slightly caught in the mouth of the

opening, then they will not become permanently wedged between two bars. The wedge allows it to pass through if it is just barely passable going through the opening. The material that passes through is finer than gravel. The sand, 2 millimeters and finer, goes into a sump and then goes onto the next device. The gravel and material larger than 2 millimeters go into a rotating drum where they tumble around for up to 15 minutes, then are passed to a second screen for a final washing prior to being discharged down the chute into a hopper. This produces a gravel mix that has the majority of its finer than 2 millimeter material removed. The less than 2 millimeter material then passes on into this device which is basically a froth flotation unit with hydrocyclones. The fluid swirls around inside the apex. The bottom of the hydrocyclone is where the concentrated slurry of the material passes. None of these hydrocyclones can work beyond a 10 percent slurry.

Figure 37. Cyclone.



This process removes the coarser fractions in the hydrocyclones. Hydrocyclones basically operate within the sand region, and if there is material that is finer than sand (material that passes a 200 mesh screen), then approximately 100 percent of that material will pass out the top. The finer fractions and the wastewater that overflow from the hydrocyclone are not treated any further. The contaminants that reside on the finer fractions adhere fairly well to such particles, therefore, it does not make any processing sense to try and remove them. The coarser fractions then subsequently move down into the next cells. The fluid movement from right to left and the solid

Figure 38. Jigging.

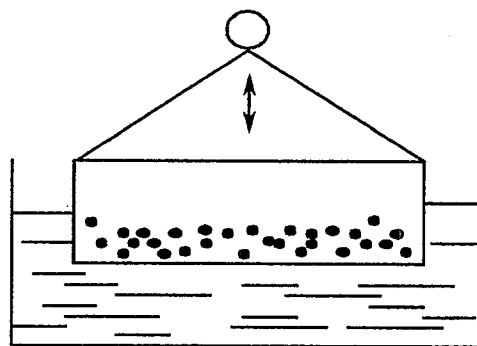
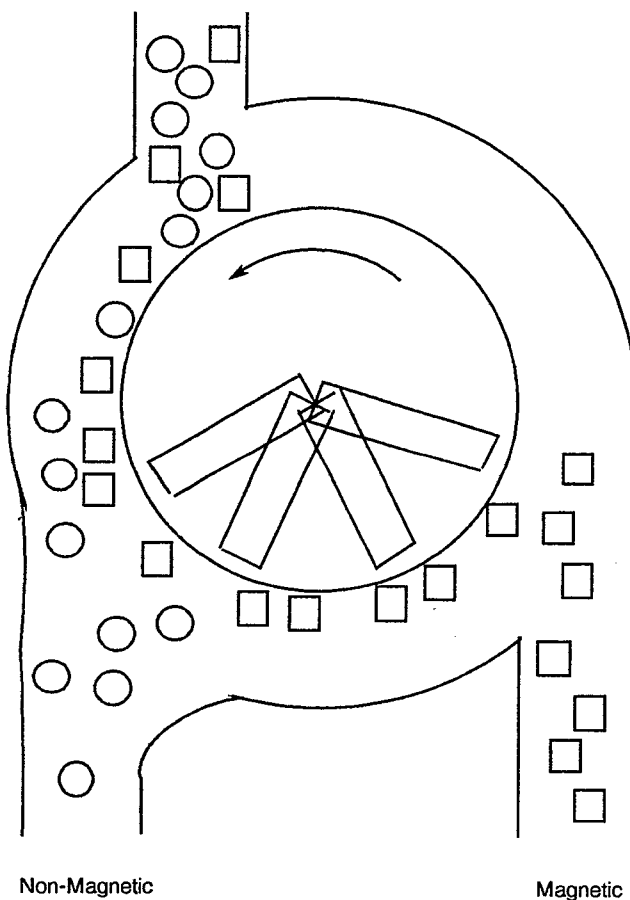


Figure 39. Magnetic separator.

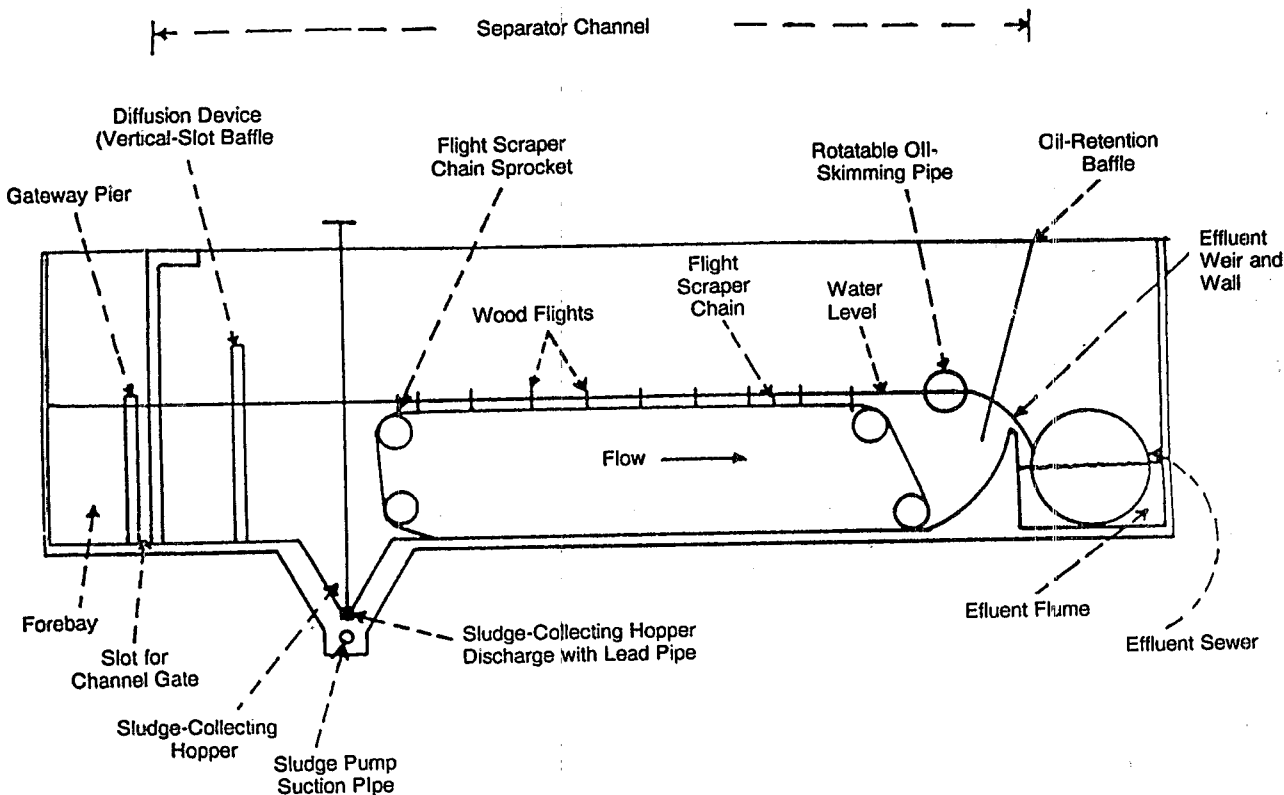


movement from left to right (as they pass through each of these hydrocyclones) gives this device its name, a countercurrent unit. The coarse fractions pass through the cleanest water just prior to leaving the system and the finest fractions traveling away from the system in the direction of the most contaminated fluids.

Gas Separation

Gas separation can be achieved with centrifugal separation techniques. Gas is forced through a

Figure 40. API oil/water separator.



separation nozzle which is circular in shape. The input gas is entered at supersonic speed and the higher density material tends to go to the outside of the separation nozzle and the less dense remain on the inner side. The separation knife will then shear the heavy fraction on the outside from the lighter inner fraction (Figure 43).

Solidification/Stabilization Processes (Post Treatment Options)

Solidification/stabilization technologies are techniques designed to be used as final waste treatment. A major role of these processes is post-treatment of residuals produced by other processes such as incineration or chemical treatment. In some cases, solidification/stabilization processes can serve as the principal treatment of hazardous wastes for which other detoxification techniques are not appropriate. High volume, low toxicity wastes (such as contaminated soils) are an example of this application.

The intent of solidification/stabilization processes is to immobilize these toxic or hazardous constituents in a waste by:

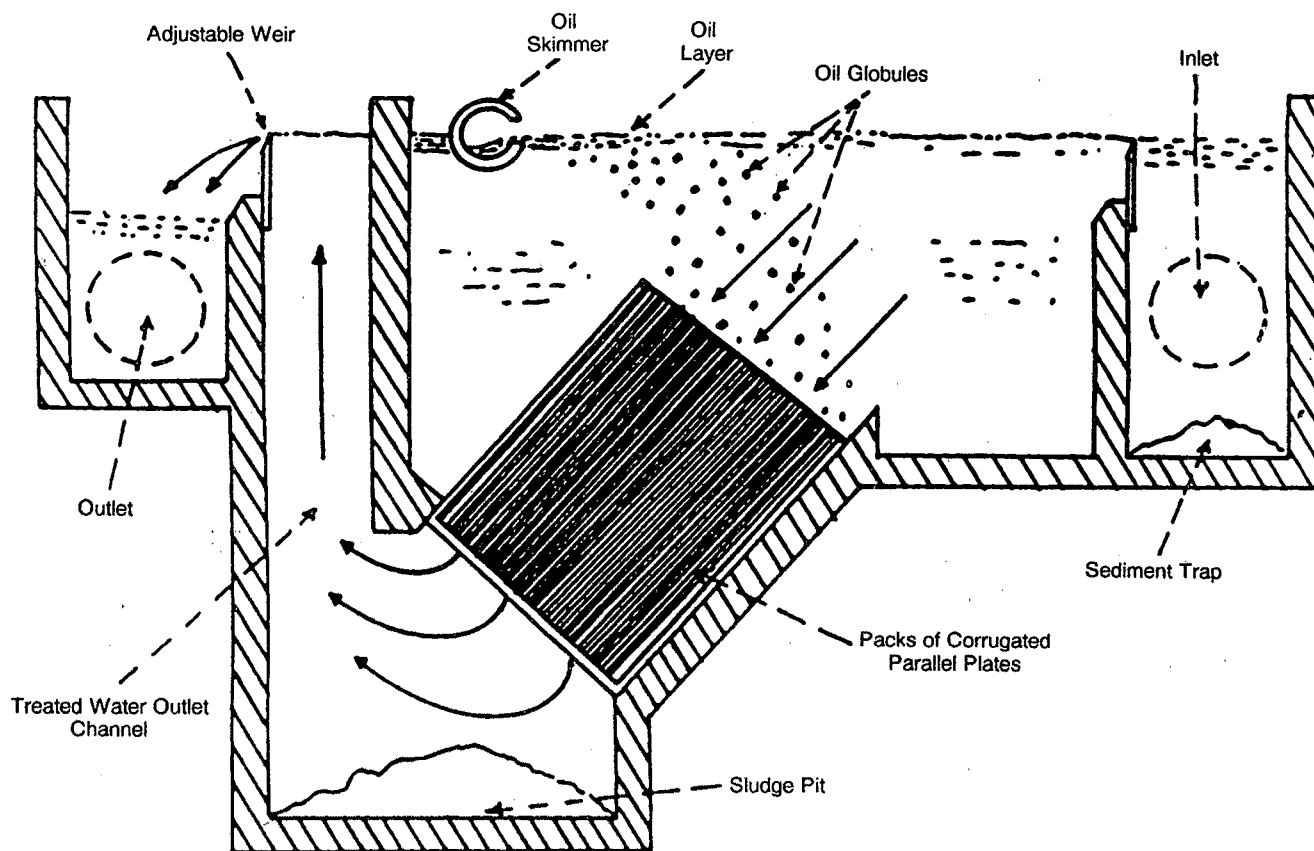
- Changing the constituents into immobile (insoluble) forms;

- Binding them in an immobile, insoluble matrix; and/or
- Binding them in a matrix which minimizes the waste material surface exposed to solvent.

Often, the immobilized product has a structural strength sufficient to prevent fracturing over time. Solidification accomplishes the objective by changing a non-solid waste material into a solid, monolithic structure that ideally will not permit liquids to percolate into or leach materials out of the mass. Stabilization, on the other hand, binds the hazardous constituents into an insoluble matrix or changes the hazardous constituent to an insoluble form. Other objectives of solidification/stabilization processes are to improve handling of the waste and produce a stable solid (no free liquid) for subsequent use as a construction material or for landfilling.

As a first step in the selection process, the applicability of the various solidification/stabilization processes for specific contaminants can be determined using Table 12. Since these waste treatment systems vary widely in their applicability, cost, and pretreatment requirements, many are limited as to the types of waste that can be economically processed. Waste characteristics such as organic content, inorganic content, viscosity and

Figure 41. Shell corrugated-plate interceptor.

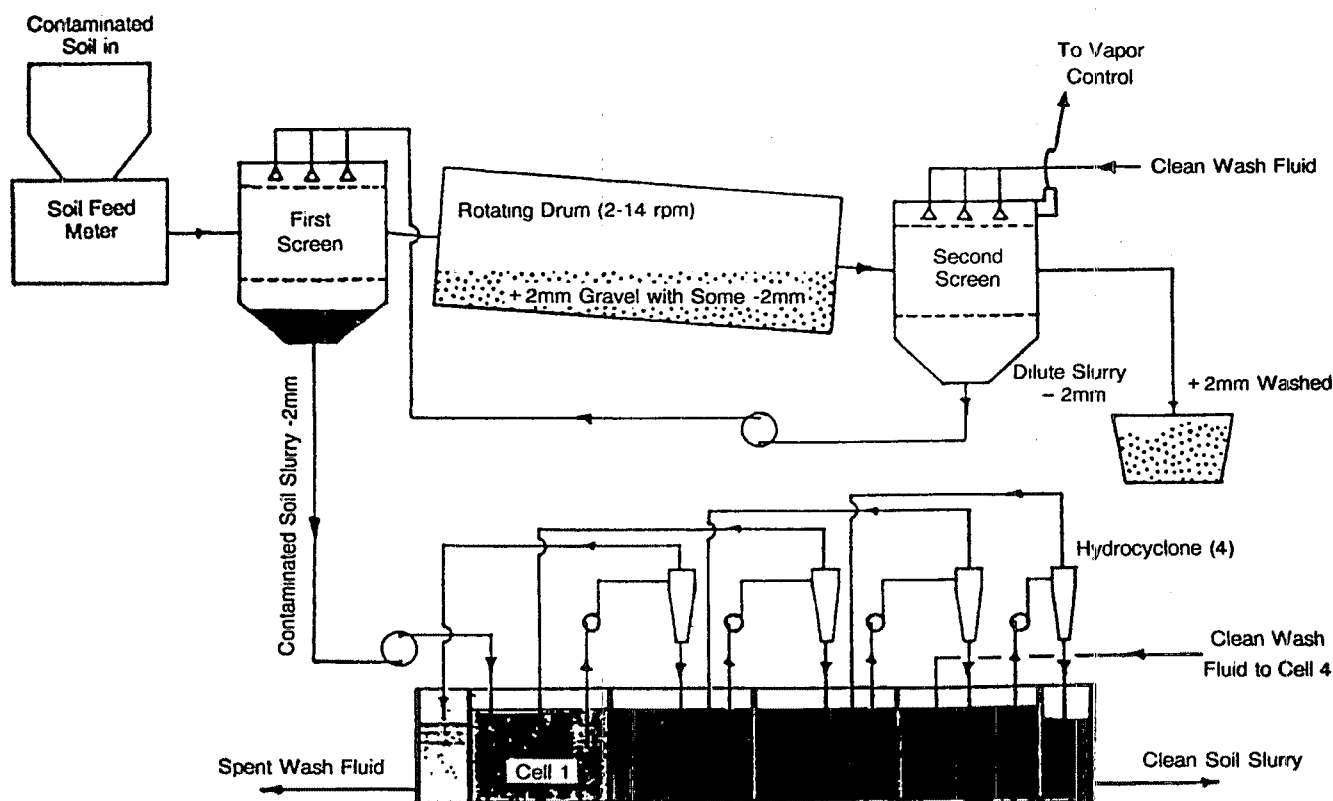


particle size distribution can affect the quality of the final solidified product. These characteristics inhibit the solidification process by affecting the compatibility (or incompatibility) of the binder and the waste, and the completeness of encapsulation and development of preferential paths for leaching due to spurious debris in the waste matrix. Selection of any particular technique for waste treatment must include careful consideration of the intended purpose for the action, the cost of processing, the increase in bulk of material produced and the changes in the handling characteristics of the resultant by-products. The design and location of any placement area or landfill that eventually receives the treated waste is also a major consideration in deciding on the physical properties that will be required of the stabilization process.

Solidification/stabilization processes are not "off-the-shelf" technologies, thus, it is not unusual for modifications to the additives required for a specific waste. For this reason, some pilot testing of the solidification reagents may be required to develop the ultimate characteristics desired in the final product.

As part of the quality control procedures for solidification technologies, raw materials used must be checked as well as the waste and the final product. The raw materials may vary from supplier to supplier and from batch to batch. In order to achieve a consistent solidified product, tests should be run to check raw material inputs and match them to plant operations. More important, the waste must be tested before processing. To this end, samples are taken for treatability studies during the facility investigation as well as during processing of the waste on a routine basis. When an incoming waste is received at a solidification treatment facility, it must be rapidly tested for selected parameters which may interfere with the solidification process. This testing can be complicated, and there is little time available to match the incoming wastes' characteristics with those previously determined to be acceptable for a solidification process designed specifically for the waste. The waste characteristics must be consistent between shipments (within an acceptable range); if it does not meet the requirements, the shipment may be rejected on this basis. As a last quality check, the final product must undergo preselected physical and

Figure 42. Mobile soils washing system.



chemical tests, and the results must fall within acceptable ranges.

Physical and chemical tests of the final product may need to address two concerns: (1) whether the solidified waste exhibits any RCRA defined toxicity characteristics or could be delisted; and (2) the potential long term fate of treated materials in the disposal environment. Three tests are available which address the first concern. These are the Extraction Procedure (EP Tox) (40 CFR 261, Appendix II, 1980) and the Toxicity Characteristic Leaching Procedure (TCLP) (40 CFR 261, Appendix II, 1986), and the Multiple Extraction Procedure Test (40 CFR 261, Appendix II, January 1989). It is important to note that these tests are not indicators of expected leachate quality but of potentials. A solidified product which cannot pass the appropriate test (EP Tox or TCLP) would be subject to classification as a hazardous waste.

A wide variety of tests may be useful in assessing the long term fate of a solidified product. An appropriate

combination of tests would depend on the nature of the waste, the treatment technology employed, and the final disposal environment of the treated waste. Performance test methods for a number of these testing procedures are currently being evaluated by the U.S. EPA Risk Reduction Engineering Laboratory in Cincinnati, Ohio. General information is provided through the Handbook for Stabilization/Solidification of Hazardous Wastes (U.S. EPA, 1986).

Available Solidification/Stabilization Technologies and Their Application

Major categories of industrial waste solidification/stabilization systems are cement-based processes, pozzolanic processes (not including cement), thermoplastic techniques, organic polymer techniques, surface encapsulation techniques, and self-cementing techniques (for high calcium sulfate sludges). Vitrification (discussed previously) can also be considered a solidification process.

Figure 43. Separator nozzle.

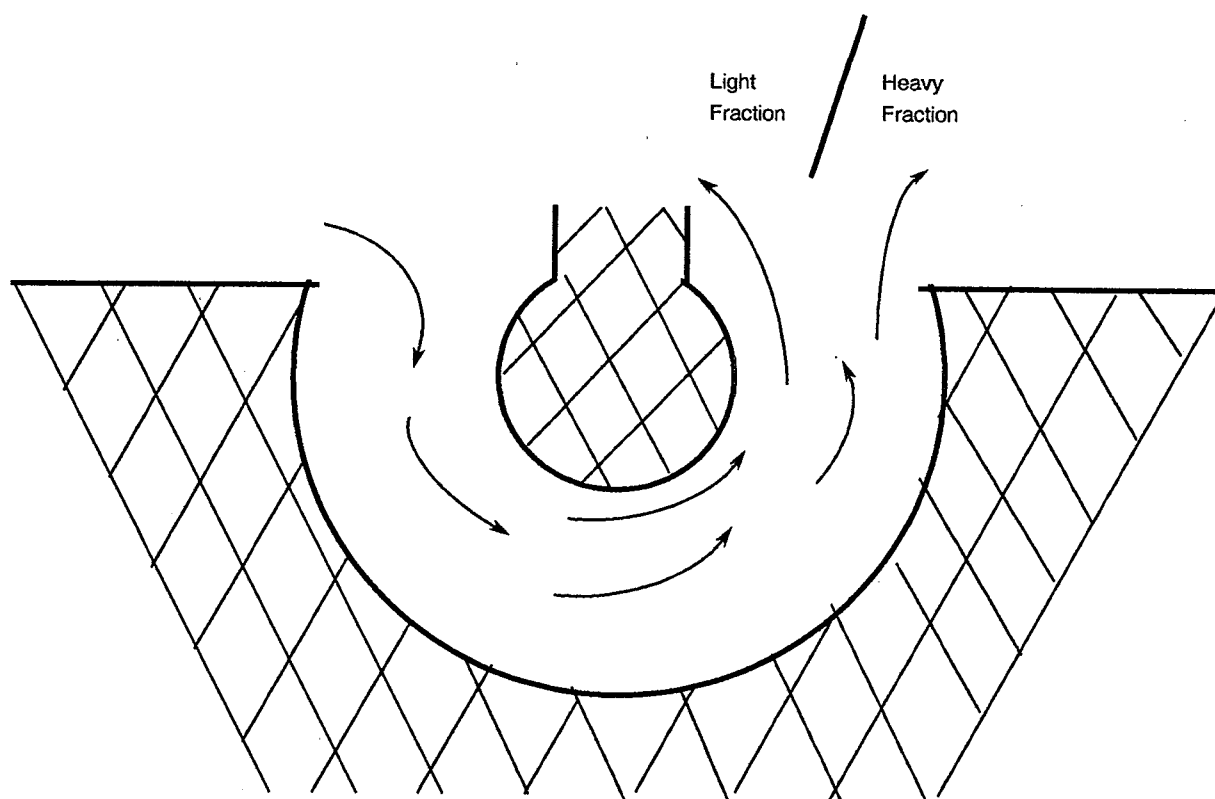


Table 12. Applicability of Solidification/Stabilization for Specific Contaminants

Process	Heavy Metals	Organic Solvents ^a	Solid Organics (excluding explosives)	Acidic Wastes (from explosives manufacturing)	Oxidants	Sulfates
Micro-encapsulation						
Asphalt-based	Applicable	Applicable	Applicable; contaminant may act as a binding agent	Applicable if waste is first neutralized	Not applicable	Not applicable
Polymer-based	Applicable	Applicable; impeded setting ^b	Applicable; impeded setting	Applicable	Not applicable	Applicable
Macro-encapsulation with polyethylene	Applicable	Applicable if contaminant is adsorbed onto a solid	Applicable	Applicable if waste is first neutralized	Not applicable	Applicable
Stabilization						
Cement-based	Applicable	Applicable; impeded setting	Applicable	Applicable (contaminant is neutralized by the basic cement)	Applicable	Applicable if an additive used to prevent spalling
Pozzolanic	Applicable	Applicable; impeded setting	Applicable	Applicable	Applicable	Applicable

^a May volatilize upon heating.

^b "Impeded setting" does not preclude the existence of an additive that could counteract this effect.

Source: R.F. Weston

Cement-based Pozzolan

Technology Description: To understand the cement-based pozzolan solidification/stabilization process, it is necessary to first understand the binding material. Common (portland) cement is produced by firing a charge of limestone and clay or other silicate mixtures in a kiln at high temperatures. The resulting clinker is ground to a fine powder to produce a cement that consists of approximately 50 percent tricalcium and 25 percent dicalcium silicates (also present are about 10 percent tricalcium aluminate and 10 percent calcium aluminoferrite). The cementation process is brought about by the addition of water to the anhydrous cement powder. This first produces a colloidal calcium silicate-hydrate gel of indefinite composition and structure. Hardening of the cement is a lengthy process brought about by the interlacing of thin, densely packed, silicate fibrils growing from the individual cement particles. This fibrillar matrix incorporates the added aggregates and/or waste into a monolithic, rock-like mass.

A number of additives (many proprietary) have been developed for use with cement to improve the physical characteristics and to decrease the leaching losses from the solidified mass. Experimental work on the treatment of radioactive waste has shown that nuclear waste retention improvements can be achieved by cement-based stabilization processes with the addition of clay or vermiculite as absorbents. Soluble silicates have reportedly been used to bind contaminants in cement solidification processes, but this additive causes an increase in volume to occur during the setting of the cement-waste mixture. A recently proposed modification of this technique involves dissolving the metal-rich waste with fine-grained silica at low pH and then polymerizing the mixture by raising the pH to 7. The resulting contaminated gel is mixed with cement and hardens within 3 days. The equipment used for the cement-based pozzolan process is similar to that used in a cement batching plant as illustrated in Figure 44.

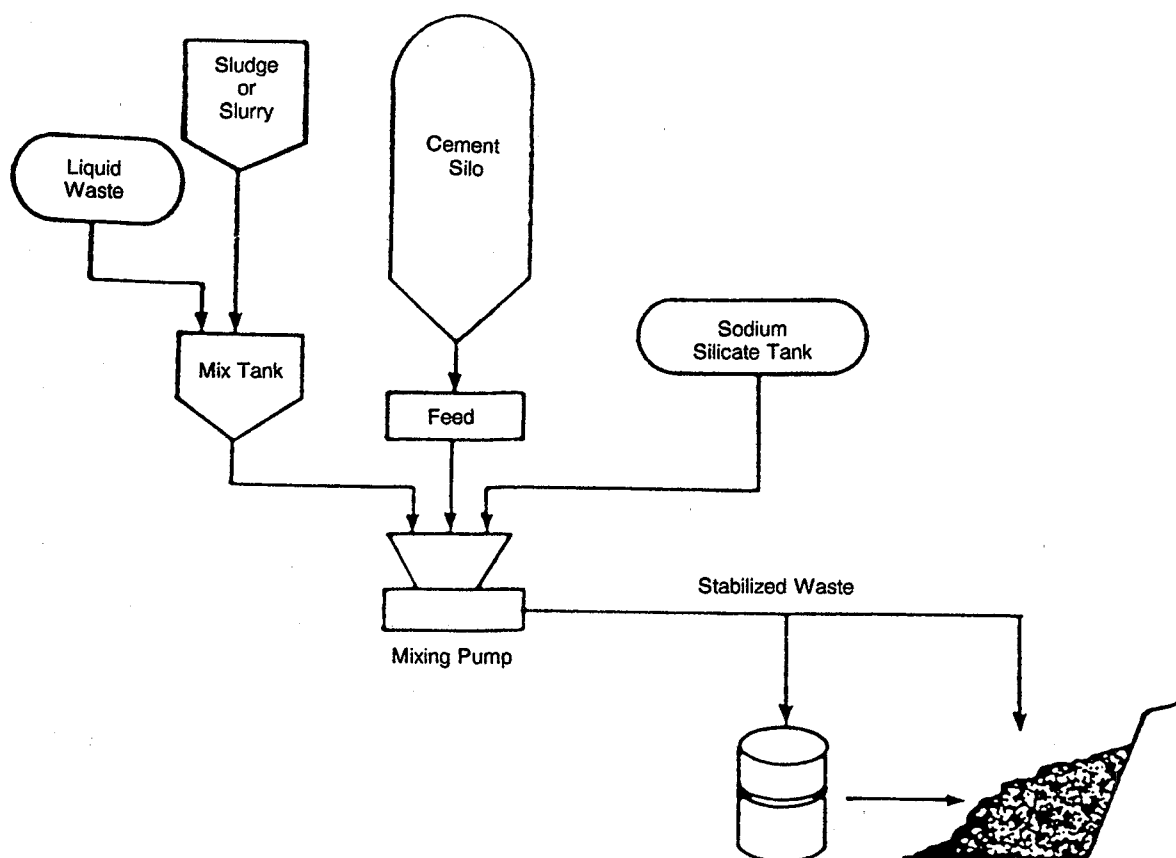
Applicability: Most hazardous waste slurried in water can be mixed directly with cement, and the suspended solids will be incorporated into the rigid matrices of the hardened concrete. This process is especially effective for waste with high levels of toxic metals since at the pH of the cement mixture, most multivalent cations are converted into insoluble hydroxides or carbonates. Metal ions also may be incorporated into the crystalline structure of the cement minerals that form. Materials in the waste (such as sulfides, asbestos, latex and solid plastic wastes) may actually increase the strength and stability of the waste concrete. It is also effective for high-volume, low-toxic, radioactive wastes.

The presence of certain inorganic compounds in the hazardous waste and the mixing water can be deleterious to the setting and curing of the waste-containing concrete. Also, impurities such as organic materials, silt, clay or lignite may delay the setting and curing of common portland cement for as long as several days. Dust-like, insoluble materials passing through a No. 200 mesh sieve (74×10^{-6} m particle size) are undesirable, as they may coat the larger particles and weaken the bond between the particles and the cement. Soluble salts of manganese, tin, zinc, copper and lead may cause large variations in setting time and significant reduction in physical strength. In this regard, salts of zinc, copper and lead are the most detrimental. Other compounds such as sodium salts of arsenate, borate, phosphate, iodate and sulfide will retard setting of portland cement even at concentrations as low as a few tenths of a percent of the weight of the cement used. Wastes containing large amounts of sulfate (such as flue-gas cleaning sludges) not only retard the setting of concrete, but, by reacting to form calcium sulfoaluminate hydrate, cause swelling and spalling in the solidified waste-containing concrete. To prevent this reaction, a special low-alumina cement was developed for use in circumstances where wastes containing high sulfate levels are encountered.

Advantages: Cement-based solidification systems are an economically feasible process having the following advantages:

- (1) The amount of cement used can be varied to produce high-bearing capacities thereby making the waste/concrete material a good subgrade and subfoundation material.
- (2) Low permeability in the product can also be achieved by varying the amount of cement used.
- (3) Raw materials are plentiful and inexpensive.
- (4) The technology and management of cement mixing and handling is well known; the equipment is commonplace and specialized labor is not required.
- (5) Extensive drying or dewatering of the waste is not required because cement mixtures require water in the hydration process, and thus the amount of cement added can be adjusted to accommodate a wide range of waste water contents.
- (6) The system is tolerant of most chemical variations. The natural alkalinity of the cement used can neutralize acids. Cement is not affected by strong oxidizers, such as nitrates or chlorates.

Figure 44. Cement-based stabilization process (Roy F. Weston).



- (7) Pretreatment is required only for materials that retard or interfere with the setting action of cement.
- (8) Leaching characteristics can be improved, where necessary, by coating the resulting product with a sealant.

Disadvantages: Disadvantages include the fact that relatively large amounts of cement are required for most treatment processes (but this may partly be offset by the low cost of material). The weight and volume of the final product is typically about double those of other solidification processes. Uncoated cement-based products may require a well-designed landfill for burial. Experience in radioactive waste disposal indicates that some hazardous constituents are leached from the solidified concrete, especially by mildly acidic leaching solutions. Extensive pretreatment and the use of more expensive cement types or additives may be necessary for waste containing large amounts of impurities, such as borates and sulfates which can effect the setting or curing of the waste-concrete mixture. If ammonia is present in the waste, the alkalinity of cement drives

off ammonium ions as ammonia gas. Finally, if energy cost increases dramatically, the cost of cement will likely follow because cement is an energy-intensive material.

Corrective Action Application: At the James River site in Virginia, cement-based solidification was performed on kepone-contaminated sediment. Testing indicated that the cementitious agents were ineffective in reducing kepone concentrations in water leachate (Tittlebaum et al., 1985). This was attributed to the high pH of the cementitious stabilization agents required in the curing process. Although the elevated pH proved to effectively contain heavy metals, it resulted in increasing the water solubility of the kepone in the sediment (Tittlebaum et al., 1985). This example serves to show how contaminant-specific, cement-based solidification processes are.

Pozzolanic Processes (Not Containing Cement)

Technology Description: Waste solidification techniques based on lime products usually depend on the reaction of lime with a fine-grained silica

(pozzolanic) material and water to produce a concrete-like solid (sometimes referred to as a pozzolanic concrete). The most common pozzolanic materials used in this solidification process are fly ash, ground blast-furnace slag and cement-kiln dust. All of these materials are themselves waste products with little or no commercial value. The use of these waste products to consolidate another waste is often advantageous to the processor, who can treat two waste products at the same time. For example, by making use of the pozzolanic reaction, power-plant fly ash can be combined with flue-gas-cleaning sludge and lime (along with other additives) to produce an easily handled solid. Figure 45 illustrates the configuration of equipment used for this process.

Applicability: Pozzolanic processes are suitable for high-volume, low-toxicity wastes containing radioactive materials or heavy metals with an organic content below 10 percent.

Advantages: The advantages of lime-based solidification techniques that produce pozzolanic concrete are: solidified material produced has improved handling and permeability characteristics; materials required for the process are often very low in cost and widely available; little specialized equipment is required for processing; the chemistry of lime-pozzolanic reactions are relatively well-known; sulfate content of the waste does not cause spalling or cracking; and extensive dewatering is not necessary because water is required in the setting reaction.

Disadvantages: The lime-based systems have many of the same potential disadvantages as cement-based techniques including: the lime and other additives add to the weight and bulk of the resultant product to be transported and/or landfilled; uncoated lime-treated materials may require specially designed landfills to guarantee that the material does not lose potential pollutants by leaching; the process is temperature sensitive; the waste may require pretreatment; the setting characteristics of the pozzolanic concrete are sensitive to organic content; and the process has a potential for producing fugitive dust emissions.

Corrective Action Application: In Massachusetts, a municipal wastewater treatment plant receives a number of wastestreams containing heavy metals from local industries. When tested, the dewatered sludge failed the EP toxicity test. In order to permit landfill disposal of the sludge, solidification processes were examined. A soluble, silicate-based system, developed by Chemfix, was ultimately selected which produced a product whose leachate passed the EP toxicity test (Sullivan, 1984).

Cement-Pozzolanic Processes

Certain treatment systems fall in the category of cement-pozzolanic processes and have been in use for some time outside the U.S. In these systems, both cement and lime-siliceous materials are used in combination to give the best and most economical containment for the specific waste being treated. In general, the bulk of the comments (under both classifications above) hold for techniques using a combination of treatment materials.

Thermoplastic Microencapsulation

Technology Descriptions: The use of thermoplastic solidification systems in radioactive waste disposal has led to the development of waste containment systems that can be adapted to industrial waste. In processing radioactive waste with bitumen or other thermoplastic material (such as paraffin or polyethylene), the waste is dried, heated and dispersed through a heated, plastic matrix. The mixture is then cooled to solidify the mass.

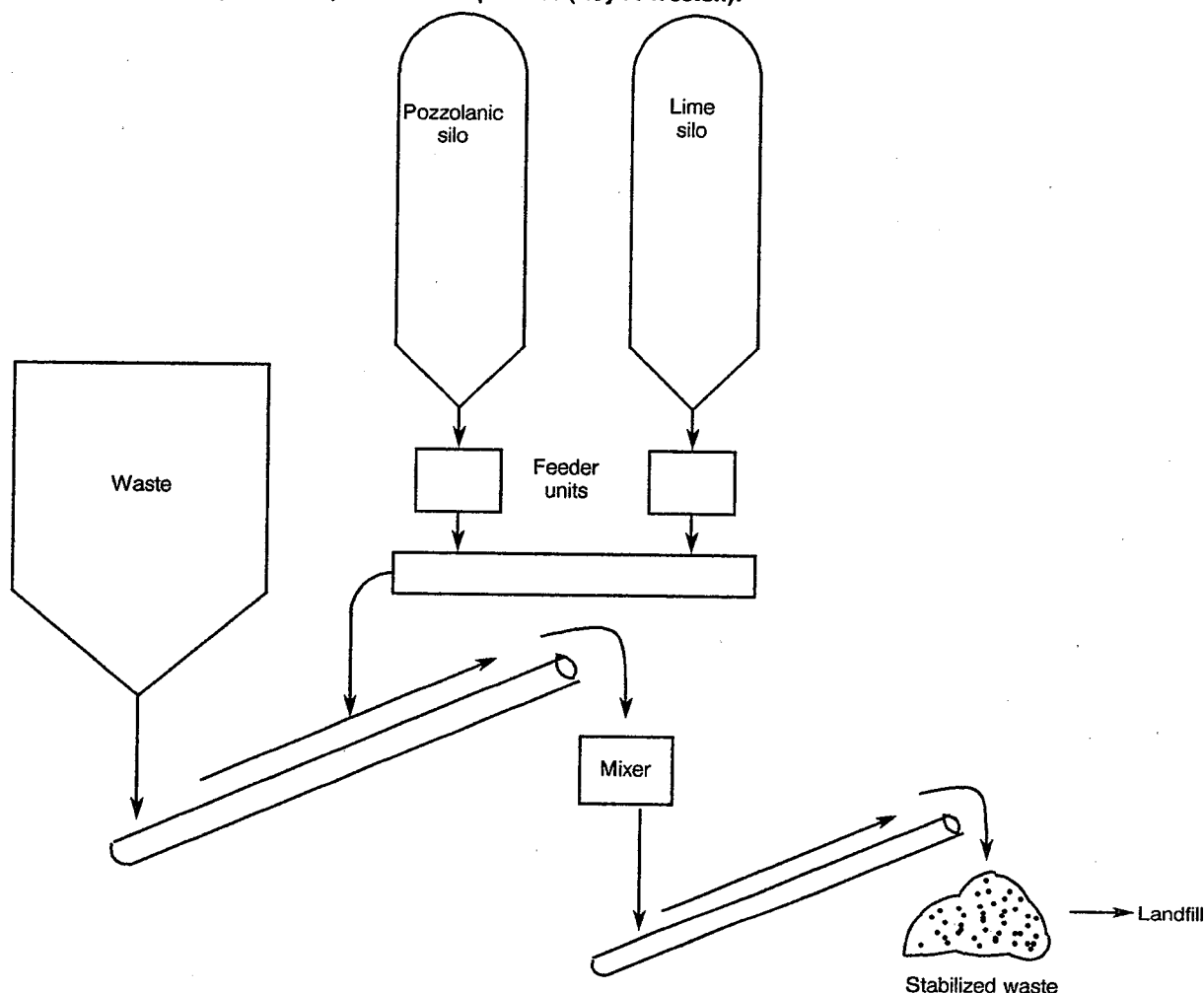
The process requires some specialized (expensive) equipment to heat and mix the waste and plastic matrices, but equipment for mixing and extruding waste plastic are commercially available. The plastic in the dry waste must be mixed at temperatures ranging from 130° to 230°C, depending on the melting characteristics of the material and type of equipment used.

A variation of this process uses an emulsified bitumen product that is miscible with a wet sludge. In this process, the mixing can be performed at any convenient temperature below the boiling point of the mixture. The overall mass must still be heated and dried before it is suitable for disposal. Ratios of emulsions to waste of 1:1 to 1:1.5 are necessary for adequate incorporation.

Applicability: Thermoplastic microencapsulation is commonly used for high-toxicity, low-volume wastes and is suitable for inorganic and most organic waste. In many cases, the waste type can rule out the use of an organic-based treatment system. Organic chemicals that are solvents for the matrix obviously cannot be used directly in the treatment system. Strong oxidizing salts (such as nitrates, chlorates or perchlorates) will react with the organic matrix materials and cause slow deterioration. At the elevated temperatures necessary for processing, the matrix-oxidizer mixtures are extremely flammable.

Leach or extraction testing undertaken on anhydrous salts embedded in bitumen as a matrix indicates that rehydration of the embedded compound can occur. When the sample is soaked in water, the asphalt or bitumen can swell and split apart, thereby greatly increasing the surface area and rate of waste loss.

Figure 45. Lime-based (pozzolanic) stabilization process (Roy F. Weston).



Some salts (such as sodium sulfate) will naturally dehydrate at the temperatures required to make the bitumen plastic; thus, these easily dehydrated compounds must be avoided in thermoplastic stabilization.

Advantages: The major advantages of the thermoplastic-based disposal systems are: by disposing of the waste in a dry condition, the overall volume of the waste is greatly reduced; most thermoplastic matrix materials are resistant to attack by aqueous solutions; microbial degradation is minimal; most matrices adhere well to incorporated materials, therefore, the final product has good strength; and materials embedded in a thermoplastic matrix can be reclaimed if needed.

Disadvantages: The principal disadvantages of the thermoplastic-based disposal systems are the following: (1) expensive, complicated equipment requiring highly specialized labor is necessary for processing; (2) the plasticity of the matrix-waste mixtures may require that containers be provided for

transportation and disposal of the materials, which greatly increases the cost; (3) the waste materials to be incorporated must be dried, which requires large amounts of energy; (4) incorporating wet wastes greatly increases losses through leaching; (5) these systems cannot be used with materials that decompose at high temperatures, especially citrates and certain types of plastics; (6) there is a risk of fire in working with organic materials such as bitumen at elevated temperatures; (7) during heating, some mixes can release objectionable oils and odors, causing secondary air pollution; (8) the incorporation of tetraborates of iron and aluminum salts in bitumen matrices causes premature hardening, and can clog and damage the mixing equipment; (9) strong oxidizers usually cannot be incorporated into organic materials without the occurrence of oxidizing reactions (High concentrations of strong oxidizers at elevated processing temperatures can cause fires.); and (10) dehydrated salts incorporated in the thermoplastic matrix will slowly rehydrate if the mixture is soaked in water. The rehydrated salt will expand the mixture causing the waste block to

fragment thereby increasing the exposed surface area.

Corrective Action Application: Documentation on the application of this technology is limited for RCRA sites.

Surface Encapsulation

Technology Description: Many waste treatment systems depend on binding particles of waste material together. To the extent to which the binder coats the waste particles, the wastes are encapsulated. However, the systems addressed by surface encapsulation processes are those in which the waste has been pressed or bonded together and then is enclosed in a coating jacket of inert material. A number of systems for coating solidified industrial waste have been examined. In most cases, coated materials have suffered from lack of adhesion between coatings and bound wastes, and lack of long-term integrity in the coating materials.

Applicability: Surface encapsulation (macroencapsulation) is appropriate for both organic and inorganic wastes.

Surface coating of concrete-waste composites has been examined extensively. The major problems encountered have been poor adhesion of the coating onto the waste or lack of strength in the concrete material containing the waste. Surface coating materials that have been investigated include asphalt, asphalt emulsion and vinyl. However, no surface coating system for cement-solidified material is currently being advertised.

Advantages: Major advantages of an encapsulation process involve the fact that waste materials never come into contact with water, therefore, soluble materials (such as sodium chloride) can be successfully surface-encapsulated. The impervious jacket also eliminates all leaching into contacting waters as long as the jacket remains intact.

Disadvantages: A major disadvantage of surface encapsulation is that the resins required for encapsulating are expensive. The process requires large expenditures of energy in drying, fusing the binder and forming the jacket. Polyethylene is combustible (with a flash point of 350°C) making fires a potential hazard. The system requires extensive capital investment and equipment. Skilled labor is required to operate the molding and fusing equipment.

Corrective Action Application: TRW Corporation has developed one type of encapsulation system (U.S.EPA 1980). The TRW surface encapsulation requires that the waste material be thoroughly dried. The dried waste is stirred into an acetone solution of modified

1,2-polybutadiene for 5 min. The mixture is allowed to set for 2 hr during which time a solid block is formed. The optimum amount of binder for encapsulation is 3 percent to 4 percent of the fixed material on a dry-weight basis. The coated material is placed in a mold, subjected to slight mechanical pressure, and heated to between 120° and 200°C to produce fusion. The agglomerated material is a hard, tough, solid block. A polyethylene jacket 2.5 mm thick is used to encapsulate the solid block and adheres to the polybutadiene binder.

No field tests or pilot applications of this process have been performed to date. The product does well in bench tests in which the polyethylene jacket remains intact. Destructive bench tests which grind the product (such as the EP Tox or TCLP) defeat the purpose of the encapsulating jacket.

Self-Cementing

Technology Description: Some industrial wastes such as flue-gas-cleaning sludges contain large amounts of calcium sulfate and calcium sulfite. A technology has been developed to treat these types of wastes so that they become self-cementing. Usually a small portion (8 percent to 10 percent by weight) of the dewatered waste sulfate/sulfite sludge is calcined under carefully controlled conditions to produce a partially dehydrated cementitious calcium sulfate or sulfite. This calcined waste is then reintroduced into the waste sludge along with other proprietary additives. Fly ash is often added to adjust the moisture content. The finished product is a hard, plaster-like material with good handling characteristics and low permeability.

Applicability: Self-cementing processes require large amounts of calcium sulfate and calcium sulfite and are appropriate for immobilizing heavy metals.

Advantages: The primary advantage for using a self-cementing process is the material produced is stable, nonflammable and nonbiodegradable. There are reports of effective heavy metal retention, which is perhaps related to chemical bonding of potential pollutants. Other advantages are: (1) no major additives have to be manufactured and shipped to the processing site; (2) the process is reported to produce a faster setting time and more rapid curing than comparable lime-based systems; and (3) these systems do not require completely dry waste because the hydration reaction uses up water.

Disadvantages: The disadvantages associated with self-cementing processes include: the self-cemented sludges have much the same leaching characteristics as cement- and lime-based systems; only high calcium sulfate or sulfite sludges can be used; and additional energy is required to produce the calcined cementitious material. The process also requires

skilled labor and expensive machinery for calcining waste and for mixing the calcined wastes with the bulk waste and the proprietary additives.

Corrective Action Application: Documentation on the application of this technology for RCRA waste is limited.

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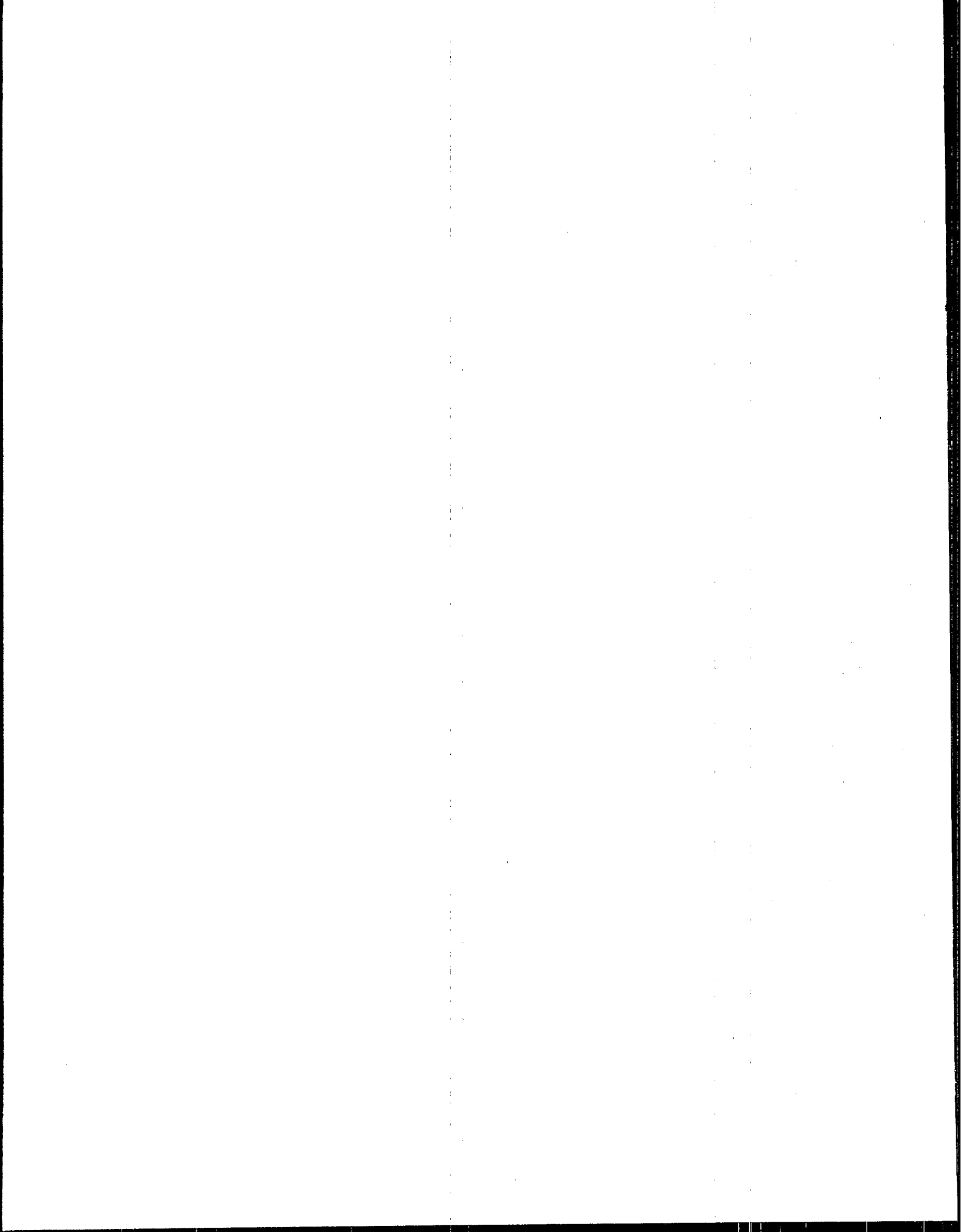
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Chapter 7

Engineering Considerations for Corrective Measures Implementation

The Corrective Measures Implementation (CMI) phase of the Corrective Action Process can present a difficult task for engineers involved in implementing the corrective action(s) selected. Up to this point, activities have been directed toward those engineering matters associated with site characterization and remedy selection, along with routine interface with the regulatory community. As the work proceeds into the corrective measure implementation (design and construction) phase, the company management becomes more involved in the process, primarily as a result of the need to commit funds. In addition, the engineer must now come face-to-face with the complexities of the site in terms of the installation of facilities. Thus, the engineer's efforts are directed toward the parallel, yet interconnected, activities associated with satisfying the regulatory requirements, dealing with management's needs, and developing facilities consistent with the site conditions. Using the elements of the Corrective Measures Implementation outlined in *RCRA Corrective Action Plan - Interim Final* (U.S. EPA, 1988) specifically the CMI Plan Development, the Corrective Measures (CM) Design and CM Construction the implications of each element can be viewed in the context of conventional engineering activities.

CMI Plan Development

From an engineering perspective, it is normal practice to identify a project management team and project strategy prior to beginning the design phase. It is at this point that the methods for handling the design, preparation of specifications, and construction are decided. In essence, a plan (although not formalized in great detail) is defined for the design phase and generalized for the construction phase. The EPA's proposed guidance suggests that the management plan for Corrective Actions be formalized similar to plans submitted for Superfund cleanup projects.

A community relations plan is suggested for corrective action projects. For most projects, such activities are reserved for public relations personnel. However, because of the technical aspects of corrective action projects, engineering attention may

be required to alleviate public concern with noise, odors and other nuisances associated with corrective action activities. It is important to work closely with the local residents so that these problems can be identified and handled effectively when they occur. For example, on one stabilization job, a new solidifying agent was brought to the site which caused some dusting problems. The dust got on a number of neighbor's cars. Because of the public participation program, the problem was quickly identified; a solution was found to prevent the dust emissions; and the contractor paid to have all of the affected automobiles cleaned. The project was only shut down for one day while the dust collecting measure was implemented. A much longer delay would have occurred without the presence of a public participation program which avoided the development of antagonism between local residents, the contractor, and the company implementing the program.

Corrective Measures Design

The design phase of an engineering project normally consists of the following activities:

- Defining the design basis.
- Preparing preliminary and detailed design drawings.
- Development of equipment lists and specifications.
- Developing material and energy balances.

Based on the in-house engineering capabilities, management philosophy, and the complexity of the project, there are a number of ways a company may wish to approach these activities. In some cases, a turnkey approach where an engineering firm is retained to design and construct the required facilities is preferred. In other cases, the design, specification, preparation and construction management activities are performed by the company, and the equipment and construction activities are purchased. However, it is not uncommon for construction of facilities to begin prior to the completion of the design. Most companies have mechanisms for the routine review of a project at various phases of completion. These project review

requirements parallel those of the regulatory community. For corrective action projects, it will be necessary to take into consideration the needs of the regulatory community in the scheduling and recording of activities as they are performed.

Operations and Maintenance Manuals are typically developed for most industrial facilities. The development of these documents usually takes place after all equipment is purchased and during the installation and shake-down of the facilities. These manuals cover normal operation and maintenance of equipment, including troubleshooting instructions and preventive and routine maintenance needs of the equipment. The items suggested in the CAP that are not normally addressed by operation and maintenance manuals are issues such as a description of potential operating problems which evolve from human health and environmental considerations; a description of alternate operating and maintenance activities which recognize possible aspects for system failure; a description of routine monitoring and laboratory testing; and a safety plan. For example, machinery that has been contaminated during remediation of the site may have to be maintained on site or decontaminated prior to maintenance. Depending on the nature of the work, the health and safety of the personnel performing maintenance may require extraordinary procedures in order to perform what may otherwise be routine tasks (e.g., lubrication of heavy equipment while wearing protective equipment).

Other engineering considerations which are routinely addressed in the design phase are the development of a project schedule and cost estimate. Most companies or contractors for those companies have developed construction quality assurance programs which are based on good engineering practice and state and local building requirements. Regulatory considerations and data reporting may impact on the quality assurance program and construction schedules. The design is based on the information generated during the facility assessment and the facility investigation. During construction, additional information is generated that may alter the process requirements and operating parameters, forcing schedule changes.

In addition to regulatory requirements, the practical matters associated with maintaining product and personnel flow to and from operating facilities must be addressed. For example, it may be difficult to remove a rail spur for remediation of a contaminated bed, if the only means to deliver a feedstock into the facility or ship a product from the facility is this rail line. In-situ flushing or some other form of non-invasive treatment would be required to address such a problem. Similarly, personnel access may have to be addressed in the planning for a corrective measures program. This is especially true in older or

more crowded facilities. People and material must be allowed to move around so that operations may continue at the facility in as normal a fashion as possible.

Corrective Measures Construction

From an engineering perspective, the general corrective measures construction activities identified in the CAP conform with typical construction management activities, but are more rigorous. The planning, inspection, and quality assurance activities in the CAP focus on issues of concern to the regulatory community to ensure that the completed corrective measures meet or exceed the cleanup objectives. In addition to the regulatory needs, the facility engineer is also concerned with these issues from the perspective of ensuring efficient construction of facilities, and that the facilities installed meet the design specifications, plant safety requirements, and building codes. As most construction projects proceed, a "punch" list of items requiring completion, modification to meet safety codes, or repairs identified during equipment checkout is developed; and system start-up and shake-down procedures are developed. Periodic review and resolution of each item is required before the construction phase is considered complete.

Another issue that the engineer must consider is the training of operating personnel. This can be handled by the contractor or by the equipment supplier. In some cases, personnel who will be responsible for the operation of the facilities are on the project team from its inception, as part of their training. In other cases, the operating team is assembled for training during the start-up and shake-down procedures. In any event, careful training of personnel before the contractor completes the project appears to be an effective way to ensure proper operation of the facility over the long term.

As with most pollution control projects, the effectiveness of the design is demonstrated by some type of performance testing. This generally occurs after the equipment is operating "normally". For corrective action projects, certain facilities (such as organized above-ground treatment systems) may be able to demonstrate effectiveness through the performance testing mechanism. However, other systems (such as groundwater pumping to control/recover a contaminant plume) may require ongoing monitoring to assess its effectiveness. Sampling and testing protocols may have to be developed and implemented to demonstrate the performance of these systems.

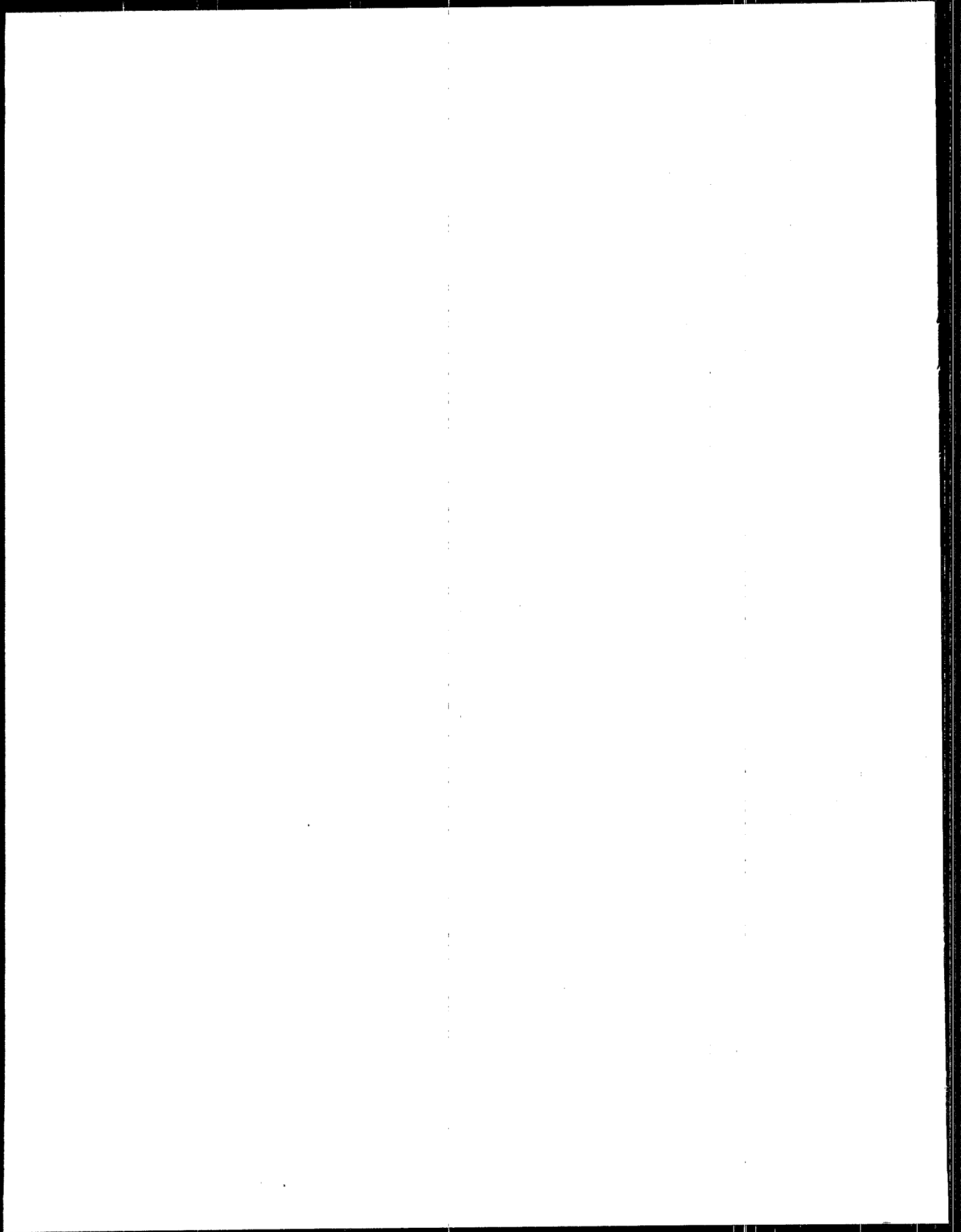
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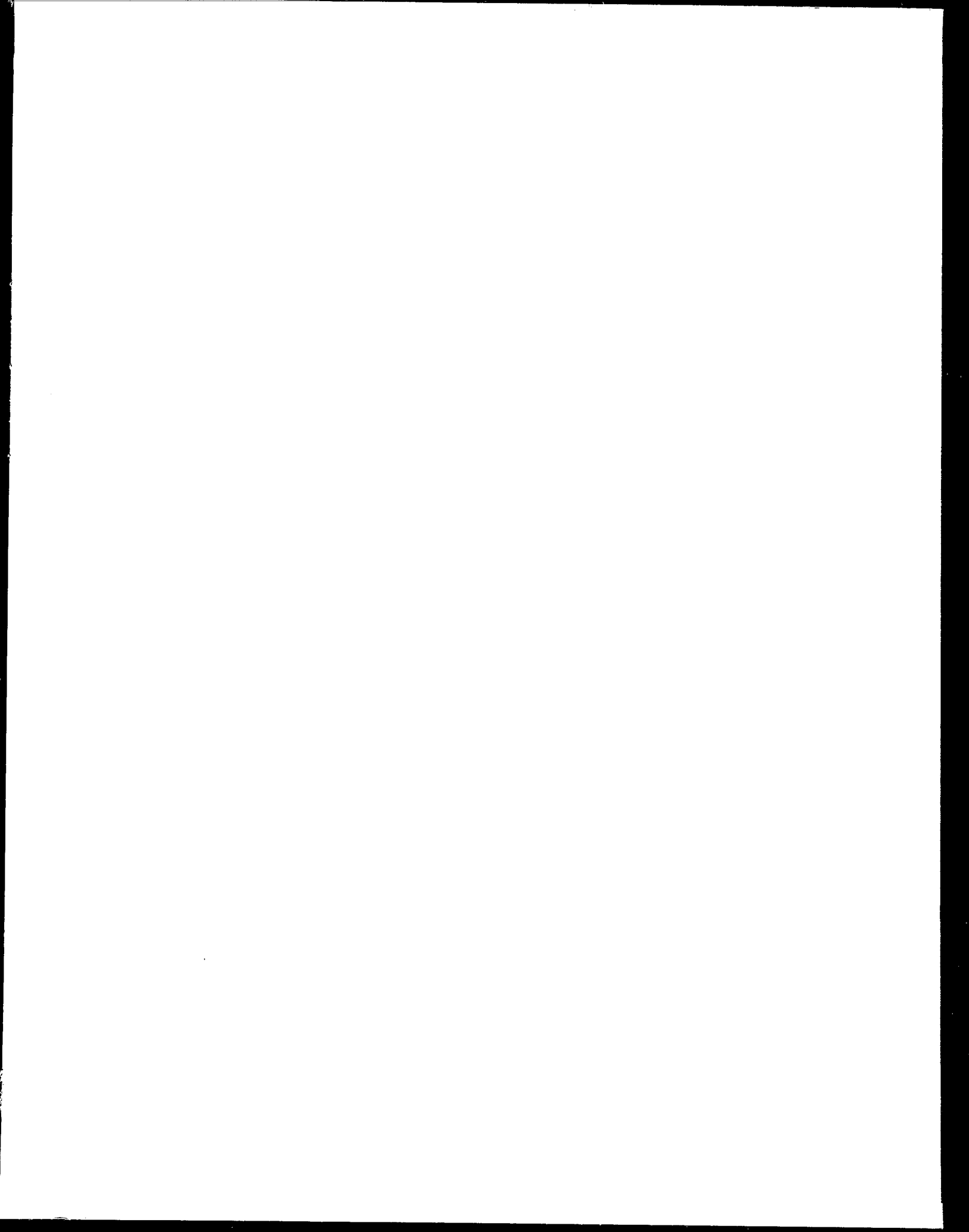
The CMI requires close cooperation between the regulatory community and the engineering and

management team of the company performing the corrective action. Through cooperation and good planning, the Corrective Action Process can proceed in a timely fashion. Without such cooperation and planning, time and money can be misdirected and necessary protection of HHE can be delayed. Thus, from the start of the Corrective Action Process, it is important to work closely with the regulatory community in all phases of the project.

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